CLIMATE CHANGE AND HEALTH IN CALIFORNIA

A PIER RESEARCH ROADMAP

CONSULTANT REPORT

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Contents

Tables

Figures

Executive Summary

This roadmap assesses the potential health impacts of global warming on California and covers both direct and indirect effects on human health, to identify research gaps and needs, and to determine priority areas to be addressed for disease prevention.

Global warming is not uniform and is subject to regional variations. California enjoys seven climate regions ranging from the hot, arid desert to cool, rainy forests. Global warming is expected to affect California via temperature and sea level rise, as well as through altered timing of annual precipitation, with extreme weather events more likely to become more intense and frequent. Subsequent health effects will likely include: heat-related and wildfire-related morbidity and mortality; casualties from extreme weather events; changed air pollution and allergen exposure; infectious diseases (particularly vectorborne and waterborne microbes); and other climate-related issues such as the effects on food productivity and safety.

Heat Waves

Increased heat waves due to climate change would cause more heat-related illnesses and deaths. Nationally, heat waves are more deadly natural disasters than hurricanes, flooding, or tornadoes. California was one of the states in the western region that showed the most extreme rise in frequency of high heat stress events and heat waves from 1949 to 1995. The U.S. Environmental Protection Agency (EPA) estimates that a 3°F warming could almost double the heat-related deaths in Los Angeles, from 70 (in 1997) to 125 (although increased air conditioning use may not have been fully accounted for). Little change in winter mortality is expected. The heat-related mortality in Los Angeles for example, would increase by 62% to 88% of current levels under global climate model (GCM) scenarios, assuming full acclimation.

Research Needs

Research needs on health effects of heat waves in California are quite similar to those identified nationally by the U.S. National Assessment, and include:

- Determining which weather parameters contribute most to morbidity and mortality, thereby improving predictions and early warning potential. For example, determining which of the current heat indices and/or synoptic air mass classifications best predict adverse health outcomes.
- Analyzing urban characteristics that are responsible for inter-city variability in heat vulnerability. These characteristics may be geographic, or related to house type or

factors associated with the urban heat island effect. Research should identify whether temperature thresholds are variable across California cities.

- Conducting additional studies focused on the association between heat and morbidity (as well as mortality).
- Evaluating the feasibility and effectiveness of specialized health education efforts aimed at reaching susceptible populations.
- Standardized reporting of heat-related mortality is lacking and requires attention. Diagnostic guidelines and criteria for use by medical examiners should be adopted.
- Assessing net annual health impacts, comparing both summer and winter mortality projections under climate change scenarios.
- Evaluating the effectiveness of current warning systems.
- Determining whether a threshold temperature exists, above which Californians may suffer adversely.

Wildfires

Wildfires are common in the hills throughout California and in the coastal communities of Southern California. Fire has always been a trait of the area's chaparral and grassland ecosystems, as well as in other parts of California's complex landscape. The largest fires in southern California have historically occurred in the autumn, when Santa Ana winds can develop with high temperatures (conditions are characterized by low relative humidity, high temperatures, and strong northeasterly winds). Modeling results showed that the most severe effects of global climate change would occur in the Sierra foothills where the predicted number of potentially catastrophic fires increased by 143% in grassland and 121% in chaparral. Conditions that are more conducive to fires can occur with hotter and drier summers and greater amount of vegetation resulting from wetter winters. Plant pests and pathogens can also raise the risk of fire by increasing the number of dead trees in an area.

Research Needs

- Because wildfires can have serious consequences for health, further research is needed to assess wildfire risks under a changed climate; particularly the effect of climate change on Santa Ana winds, winter precipitation, and peak summer temperatures.
- Study the effect of climate change on plant pest infestation.
- Smoke from wildfires can affect air quality. With more fires likely under a changed climate, the contribution of fires to health effects from compromised air quality for Californians would be an important area for further research.
- More studies are needed on morbidity from woodland fires.

Extreme Events

According to the National Aeronautics and Space Administration (NASA), extreme events rose from 0.1% of wet days per year to 1% for the decade 2040–2049, modeled under climatic change. Such is the projection for all major basins in California. By the year 2100, temperatures in California could rise by about 5°F, precipitation could increase by 20%–30%, and sea level could rise 13 to 19 inches if warming goes unchecked, according to the EPA and the Intergovernmental Panel on Climate Change (IPCC).

Wet weather is one of the root causes of landslides. California has certain land forms that are especially susceptible to landslides—most visibly the coastal bluffs and mountains. In some cases, human-caused fires, erosion, and vegetation changes make landslides more likely to occur.

Research Needs

- Improved downscaling of global climate models (GCMs) of future climate change, to reach temporal and spatial scales useful for projecting trends in regional extreme events.
- Post-disaster disease surveillance and studies on long-term health effects such as Post Traumatic Stress Disorder (PTSD). Databases should utilize standardized definitions and outputs. To fully understand climate-driven health impacts, we need long time-series of compatible data from integrated monitoring programs.
- Analyses on non–climate risk factors—such as geographical topography, stream flow velocities, and coastal/floodplain development—that modify the impact of storms. Valuation of current urban and rural development practices on risk is needed—specifically, the effects of altered land use on vulnerability to extreme weather.
- Flow studies are needed that delineate toxic releases into water supplies, and their potential health effects. Geographic Information Systems (GIS) analyses should include toxics and population densities in flood plains.
- Epidemiologic studies of the public health effects of flooding.

Air Quality

Climate change may affect exposure to air pollutants by affecting weather, anthropogenic emissions, and biogenic emissions—and by changing the distribution and types of airborne allergens. Local temperature, precipitation, clouds, atmospheric water vapor, wind speed, and wind direction influence atmospheric chemical processes, and interactions occur between local and global-scale environments.

Parts of California already have bad air quality, and most counties have higher smog levels than acceptable by California regulatory agencies. The nation's four smoggiest urban areas are all in California. Six metropolitan areas in the state are listed as having the 10 highest-ozone levels in the nation, which makes California the smoggiest state in the nation, with Southern California being the worst off. Tropospheric ozone (smog) is already a critical problem in California. The Los Angeles South Coast Air Basin is the only area in the country given an "extreme" rating for ozone concentration by the EPA.

Higher temperatures increase ozone formation at ground level when precursors and sunlight are present. If wetter conditions increase biomass, which emits ozone precursors, then air quality could deteriorate. Ozone and non-volatile secondary particulate matter (PM) will generally increase at higher temperature, due to an increased gas-phase reaction rate. Other climate/air pollution health risks involve transboundary dust, persistent pollutants, and fungal spores.

Research Needs

- Improved air pollution models in general and their linkage with climate change, including combined effects of temperature and humidity on air pollution.
- Analyses that address the association between weather and all hazardous pollutants. Most is known about the link between ozone and temperature, but even for ozone, improved modeling of stagnant air masses and emissions scenarios is needed.
- Better understanding of boundary layer dynamics.
- Climate effects on fine particulates.
- Emission scenarios that include primary and secondary pollutants stemming from altered energy demand, as well as vegetative sources.
- The interaction of ozone and direct heat effects on mortality is difficult to disentangle, but important for better prioritizing interventions during heat waves.
- Assessment of the risks of transboundary dust, as well as ozone precursors, is needed.
- More must be known about climate effects on allergens (via temperature, carbon dioxide (CO_2), or altered growing season) and soil fungi, such as that causing coccidioidomycosis; as well as about mold exposure following flooding.
- Closing gaps in the understanding of exposure patterns and health effects
- Address the balance between heavy precipitation (as a tropospheric "cleansing" mechanism) versus heat-related or stagnant air mass exacerbation of pollution.

- Determine if a link exists between stratospheric ozone and climate change and whether this link could affect the speed of ozone hole recovery.
- Assess health risks that result from the use of technological adaptations that can increase air pollution (e.g., air conditioner use). Also, if new pesticides are used as an insect control measure, assess the effects of these pesticides on human health.

Infectious Vectorborne Diseases

Western equine encephalitis (WEE) increases in cool, wet, El Niño years; whereas, St. Louis encephalitis (SLE) does so in hot, dry, La Niña years. Both WEE and SLE are caused by arboviruses. The activity of these viruses has increased in California over the last decade. Research shows a positive correlation between increased winter precipitation (or spring snow accumulation) and summer abundance of *Culex tarsalis*—a mosquito that carries the viruses that cause these diseases—meaning that prior season moisture indices may be useful predictors of summer mosquito abundance. A 3°C–5°C (5°F–9°F) increase in average temperature may cause a northern shift in the distribution of both WEE and SLE outbreaks and a decreased range of WEE in Southern California, based on temperature sensitivity of both virus and mosquito carrier. Other climate-sensitive vectorborne diseases that occur in California are: West Nile virus, malaria, tickborne diseases, plague, and hantavirus.

Research Needs

- Improvement of surveillance systems for the arthropod vector and vertebrate hosts involved in the pathogen maintenance/transmission cycles, to allow for more accurate predictive capability for epidemic/epizootic transmission. New approaches to monitoring, such as frequent and long-term sampling to monitor the full range of specific vector species, are necessary in order to provide convincing direct evidence of climate change effects.
- Improvement of active laboratory-based disease surveillance and prevention systems at the state and local level.
- System-modeling of transmission risk under future climate scenarios.
- Determination of predictable climate patterns that may provide early warning systems (e.g., the El Niño Southern Oscillation, or ENSO).
- Studies of transmission dynamics (including reservoir host and vector ecology).
- Analysis of habitat change and its effect on disease vectors and intermediate hosts.
- Improvement of rapid diagnostic tests for pathogens.
- More effective and rapid electronic exchange of surveillance data.
- Further research is needed on specific conditions that may result in outbreaks of infectious diseases such as cocci and West Nile virus. Looking into quantitative analysis of incidence data in conjunction with time-series climate data is an example.

- To better examine the relationship that exists between climatic variability and Hantavirus Pulmonary Syndrome (HPS) incidence, it may be necessary to analyze factors (e.g., temperature, precipitation, elevation, vegetation density) that may influence fluctuations in rodent populations. Weather monitoring stations, global positioning systems, vegetation surveys—as well as satellite-based remote sensors—can be used as tools for data collection.
- Reassess the appropriate levels of evidence, including dealing with the uncertainties attached to detecting the health impacts of global change. Only limited databases are available to address the health impacts of extreme climate variability and change. Much of the information comes from epidemic investigations in which researchers focus their attention on a single event and gather data for only a short period.
- A concerted effort to acquire more complete, long-term data sets is essential. Resolving the many questions about associations among weather, climate, and disease requires: (1) the identification of model systems or diseases that allows the development of long-term, high-quality data sets, and (2) sustained funding to make this research possible.

Infectious Waterborne Diseases

California's sewage and wastewater treatment systems are already overloaded and overflow with heavy rainfall. These discharges may increase as winter storms increase in frequency and intensity. Also, in Southern California, rising sea level will exacerbate saltwater intrusion into freshwater aquifers and impact the quality of surface water supplies. Data on drinking water outbreaks in the United States from 1948 to 1994 (from all infectious agents) demonstrated a distinct seasonality, a spatial clustering in key watersheds, and a statistical association with extreme precipitation. In California, HIV-infected persons and other immunocompromised individuals (e.g., cancer patients) are at high risk for serious illness or fatality from cryptosporidiosis.

Research Needs

For California, research needs are parallel with national needs, and include:

- Assessment of land use effects on water quality, through better assessment at the watershed level of the transport and fate of microbial pollutants associated with rain and snowmelt.
- Determination of high risk watersheds prone to threaten water quality under conditions of extreme climate variability.
- Studies addressing agricultural watershed protection (e.g., forested buffers) to reduce contaminated runoff from livestock operations.
- Assessment of links between altered runoff (e.g., earlier snowmelt) and water availability and quality.

- Improved surveillance and prevention of waterborne disease outbreaks, including better spatial and temporal resolution of reporting.
- Epidemiologic studies that quantify the risks associated with multiple etiologic agents.
- Molecular tracing of waterborne pathogens for accurate source identification.
- Links between drinking water, recreational exposure, and food-borne disease monitoring.
- Analysis of precipitation, streamflow, and risk from contamination of beaches during recreational use.
- Links between marine ecology and toxic algae.
- Vulnerability assessment and improved water and wastewater treatment systems.
- Event monitoring, and development and implementation of better monitoring tools for waterborne microorganisms.
- Vulnerability assessments of communities and ecosystems with respect to the effects of impaired wastewater management.
- Wastewater management also can be improved. Although most large urban centers have well-developed systems to transport, treat, and discharge wastewaters, these systems are aging and becoming overburdened by increasing population. Weather perturbations, such as increased precipitation, can increase the load to combined sewer systems and sanitary sewers through increased inflow and infiltration. To effectively treat wastewater under these conditions, facilities must increase their capacity and storage and improve their process control. Research is needed to better assess the effect of increased runoff and the capacity of these water systems to prevent contamination. Assessment of the impacts of subsurface disposal on ground water and surface microbial water quality is needed for appropriate decisions to be made regarding non-point sources for popular tourist areas and coastal communities.
- Watershed protection will continue to be an extremely important factor influencing water quality. Watershed water quality directly affects source water and finished water quality, as well as recreational sites and coastal waters. Better farming practices (to capture and treat agricultural wastes) and surrounding vegetation buffers, along with improved city disposal systems to capture and treat wastes, would reduce the runoff of nutrients, toxic chemicals, trace elements, and microorganisms flowing into reservoirs, ground water, lakes, rivers, estuaries, and coastal zones. For urban watersheds, more than 60% of the annual load of contaminant is transported during storm events. Advances in research and monitoring tied to hydrologic quantity and quality models are needed to improve

the assessment and the changes that are needed in watersheds to protect water quality for downstream users and ecosystems.

Other Infectious Agents

Increased aridity and eventual desertification from increasing temperatures may increase the potential for coccidioidomycosis (cocci). The spores of the *Coccidioides immitis* fungus is spread by dust, often preceded by increased rain. A well-documented cocci outbreak followed the 1994 Northridge, California, earthquake. Global warming and population growth in arid areas such as the Southwest United States are likely to increase the risk of such hazards.

Research Needs

- Geographical analysis of cocci incidence in California can be compared to another endemic region to assess different incidence patterns across varied geology, topography, and land use. A predictive model of *C. immitis* response to climate can be developed through analysis of climate and cocci data.

Other Climate-related Health Issues

According to the National Agriculture Assessment Group, climate change is expected to bring an increase in pest problems for most locations and most crops studied. If an increase in pesticides is used to counteract the increase in pest problems, the people of California could be more significantly affected than other areas of the country due to the large amount of land in agricultural use in California. A variety of pesticides have been linked directly to human disease and many can harm ecosystems, which could then have indirect (but significant) effects on humans.

As a result of changes in ocean conditions, the distribution and abundance of major fish stocks will probably change substantially. Increased warming of the waters off Los Angeles have resulted in a 50% decline of cold-water, northern fish species (like the greenspotted rockfish), while warm-water southern fish species (like the Garibaldi) have increased by 50%.

To date, 12 California counties have reported the presence of "killer bees" (Africanized Honey Bees, or AHBs). In theory, if climate change leads to wet winters and springs in Southern California, wildflower blooms could alter the distribution of AHBs. Snake bites may follow extreme events such as hurricanes, presumably responding to a change in their habitat caused by changes in rainfall or disturbed nests. Extreme weather events, particularly El Niño-type events, may become more common in California as a result of climate change.

Research Needs

- Plant pathogens and pests respond to climate; therefore, there is a need to estimate the changing demands for pesticides.
- Further analyses of the effectiveness of Integrated Pest Management (IPM).
- Sea surface temperature's effect on toxic algae and production of fisheries.
- Ecological studies on hazardous insects and reptiles (e.g., bees and snakes) in response to climate variability.

Conclusion

In California, climate change will contribute to both direct and indirect impacts on human health, as listed above. However, California is uniquely interconnected across many sectors, such as agriculture, fisheries, transportation, recreation, energy, and health. According to the California report of the U.S. National Assessment, "Economy, infrastructure, and natural systems are inextricably linked in California, and a clear understanding of the dynamics of these systems is imperative for the development of informed and systematic response and adaptive strategies." It is therefore essential to further consider integrated assessment modeling of many of the above-listed specific recommendation points. In addition, a general recommendation is to consider the most vulnerable populations for a given risk (and these are discussed in the full report). In many cases, these indirect impacts may be the largest, and yet the most difficult, to study without truly integrated and interdisciplinary research teams.

This roadmap recommends that the following objectives be addressed:

Proposed research areas

Objective	
5.1.1.A	Evaluate the effect of heat waves on human health, as well as the current methods and tools for addressing those impacts.
5.1.2.A	Assess climate change's contribution to wildfire risk and the impact of wildfires on human health.
5.1.3.A	Study the contributions of extreme climatological events on human health in California, and improve methods for modeling and predicting public health impacts.
5.1.4.A	Study the effects of climate change on air quality.
5.1.4.B	Study the impacts of climate change-related shifts in air quality on human health.
5.1.5.A	Better define the relationships among climate change and vector ecology, and how those relationships affect the transmission of infectious vectorborne diseases.
5.1.5.B	Improve monitoring, diagnostic, and evaluation tools.
5.1.5.C	Improve data and modeling that addresses infectious vectorborne diseases.
5.1.6.A	Evaluate the cause and effect relationships and risks of various climate change-related factors on infectious waterborne diseases.
5.1.6.B	Identify high-risk watersheds in California.
5.1.6.C	Evaluate and improve tools and methods for addressing infectious waterborne diseases.
5.1.7.A	Conduct studies and develop tools to evaluate the potential spread of cocci in California as a result of climate change.
5.1.8.A	Evaluate the effect of climate change on pests, pesticides, and their ecological effects.

Roadmap Organization

This roadmap is intended to communicate to an audience that is technically acquainted with the issue. The sections build upon each other to provide a framework and justification for the proposed research and development.

Section 1 states the issue to be addressed. *Section 2: Public Interest Vision* provides an overview of research needs in this area and how PIER plans to address those needs. *Section 3: Background* establishes the context of PIER's climate change work addressing health issues. *Section 4: Current Research and Research Needs* surveys current projects and identifies specific research needs that are not already being addressed by those projects. *Section 5: Goals* outlines proposed PIER-EA activities that will meet those needs. *Section 6: Leveraging R&D Investments* identifies methods and opportunities to help ensure that the investment of research funds will achieve the greatest public benefits. *Section 7: Areas Not Addressed by this Roadmap* identifies areas related to climate change and health research that the proposed activities do not address. *Appendix A: Current Status of Programs* offers an overview of work being done to address climate change and health. *Appendix B: Health-related Climate Change Publications* outlines a broad research base on this topic.

1. Issue Statement

There is a need for improved methods, tools, and data to identify and address health-related impacts of climate change on California.

2. Public Interest Vision

The California Energy Commission's Public Interest Energy Research (PIER) program focuses on better understanding and addressing the environmental effects of electricity generation, distribution, and use. Electricity powers innumerable technologies that support the health and well-being of the state's citizens; however, the generation of that electricity with fossil fuels releases emissions that can adversely affect the public health in a variety of ways.

In terms of climate change, those adverse impacts can result from the release of carbon dioxide (CO_2) and other greenhouse gases (GHGs) that trap heat in the Earth's atmosphere and contribute to atmospheric warming. Because that warming affects the state's climate in ways that can affect human health, it is necessary to better examine the relationship between climate change and health—to identify potential health issues, determine the extent of those issues, and identify measures that will prevent or mitigate the health-related impacts of climate change.

To help ensure that California can continue to produce sufficient energy to meet its growing needs while minimizing the impacts of climate change on human health, research and development is needed in a number of areas. Potential health threats include impacts from heat waves, wildfires, extreme weather events, air quality, and infectious diseases, among others.

In the area of heat waves, research should be conducted to determine how increased heat waves could affect health, evaluate the effectiveness of early warning systems and health education efforts, and assess the relationship between heat and morbidity and mortality. Wildfire-related research should assess wildfire risk attributable to climate change, study how climate change could affect plant pest infestation (which could increase fuel loading, from dead and dying trees), and determine the effect of wildland fires on morbidity and mortality. Climate change-related air pollution research should address a host of issues, some of which are already being addressed by other areas within PIER-EA and by other state agencies. Air pollution issues include: evaluation of the relationship between climate change and air pollution, improving modeling and emission scenarios, examining the health risks from technologies that are used to address warming (e.g., increased air conditioning), and determining the relationship between ozone and direct heat effects and mortality, among others.

For infectious vectorborne diseases, it is important to: study transmission dynamics under a changing climate; determine with more accuracy the specific conditions that result in outbreaks of infectious diseases and that increase populations of vectors such as rodents; improve surveillance systems and rapid diagnostic tests; develop more long-term, complete data sets that help resolve questions about weather and disease; and design and implement systems for rapid communication of data. Research addressing infectious waterborne diseases should examine the transport and fate of microbial pollutants associated with rain and snowmelt; identify high-risk watersheds; improve surveillance methods; conduct epidemiologic studies; better delineate exposure links; and develop better monitoring tools for waterborne microorganisms, among others. For other infectious disease issues, research should assess incidence patterns of cocci across varied geology, topography and land use; and develop a predictive model of *C. immitis* response to climate through analysis of climate and cocci data. Other climate-related health research should include: evaluating the changes in pesticide management under climate change (and its effects), evaluating the sea surface temperature's effect on toxic algae, and ecological studies on hazardous insects and reptiles in response to climate changes.

Californians will benefit from this work by gaining information on climate change-related health issues that will inform state policy decisions and improve methods and tools to address adverse impacts. This targeted research will provide a foundation on which future California-focused, climate change-related health research can be based.

The successful completion of the activities suggested in Section 5 will better inform health care providers and state agencies and decision makers of the potential existence and extent of future health problems, as they relate to the State's changing climate.

3. Background

This roadmap assesses the potential health impacts of global warming on California and covers both direct and indirect effects on human health, to identify research gaps and needs and to determine priority areas to be addressed for mitigation.

It is noteworthy to mention that global warming is not uniform and is subject to regional variations. For example, warming is occurring twice as fast during winter and nighttime periods, and winter warming is occurring faster at higher latitudes (Epstein 2001).

The State of California has the largest population, the greatest diversity of people and environments, and the largest economy in the nation. With its varying topography and its large and growing population, California is subject to a great variety of natural and technological hazards. In the last five years alone, major disasters have been declared for various kinds of events such as floods, earthquakes, wildfires, and urban riots. The western, ocean side of the state is riddled with earthquake faults from north to south (including the San Andreas and the Hayward faults) and is also subject to mudslides, landslides, and tsunami (FEMA 2003). California enjoys seven climate regions, ranging from the hot, arid desert to cool, rainy forests, as defined by the National Weather Service (NOAA 2000).

3.1 Future Climate of California

California's temperature could increase by 5°F by 2100 (National Assessment 2001). Using a range of climate models, global temperatures are expected to rise from 2.5°F to 10.4°F by the year 2100 (National Assessment 2001), and the anticipated rise in temperature due to climate change is expected to bring with it warmer and wetter winters, hotter and drier summers, and springs with a great variability—as well as an overall increase in El Niño-type conditions (USEPA 1997). Since 1900, the average temperature in Fresno has increased more than 1°F, and precipitation has decreased by up to 20% in many parts of the state. Along much of California's coast, sea level already is rising by 3–8 inches per century (3 inches for Los Angeles, 5 inches at San Francisco, and 8 inches at San Diego), and it is likely to rise by another 13–19 inches by 2100. Protecting California's coastline from a 2-inch sea level rise through 2100 could cost anywhere between $174 million to $3.5 billion (USEPA 1997).

Future climate change models projections under 2 × CO_2 emissions scenarios, for a domain centered over California, showed temperature increasing up to 3.8°C (6.8°F), with the greatest monthly surface warming at high elevations. Snow accumulation decreased, and precipitation increased in northern regions by up to 23%, on a mean annual basis (Snyder, Bell et al. 2002).

In short, global warming is expected to affect California via temperature and sea level rise, as well as altered timing of annual precipitation; extreme weather events are also likely to become more intense and frequent (NOAA 2000). Subsequent health effects will likely include: heat-related morbidity and mortality; casualties from extreme weather events; changed air pollution and allergen exposure; infectious diseases (particularly waterborne and vectorborne microbes); and effects on food productivity and safety.

3.2 The PIER Focus

Research is currently inadequate to properly address the issue of climate change impacts on health in California. The dynamics of potential health impacts that result and would result from changes in heat waves, wildfires, extreme weather events, air quality, disease transmission and exposure, and other factors remain largely unresolved. Research on various aspects of this issue is being conducted, however, because the scope of the subject is so broad, it is necessary to conduct a great deal of further research in other areas to obtain and analyze data, and to reach conclusions that can be used for state decision making.

Part of PIER's mission is to conduct and fund research in the public interest that would otherwise not occur. The issue of climate change impacts on health in California is one such issue. PIER-EA intends to address this topic through its own targeted research and to attract collaborators that will share data and work with PIER-EA to develop mitigation strategies. Whenever possible, PIER-EA will coordinate these programs and seek outside collaborators to leverage funding and avoid overlapping research.

4. Current Research and Research Needs

At present, research needs to focus on seven issues to better understand and help minimize the impact of climate change on health in California. These issues are:

1. Heat Waves
2. Wildfires
3. Extreme Events (e.g., storms, floods, landslides)
4. Air Quality
5. Infectious Vectorborne Diseases
6. Infectious Waterborne Diseases
7. Other Climate-Related Health Issues

4.1 Heat Waves

Increased heat waves due to climate change would cause more heat-related illnesses and deaths (Kalkstein and Greene 1997). In 1900, A. T. Burrows defined a *heat wave* as three or more consecutive days where the maximum shade temperature reached or exceeded 90°F (32°C) (National Weather Service undated). This definition stands today for many locales, but not for the interior of Northern California—since average high temperatures during the summer months exceed this threshold, the definition is not representative. The local definition for this unusual event is three or more consecutive days where the shade temperature reaches or exceeds 100°F (105°F for the Redding area) (National Weather Service undated).

A small increase in temperature can cause relatively large increases in the number of extremely hot days, increasing the likelihood of "killer" heat waves (Karl and Knight 1997). These increases are predominately associated with the exacerbation of preexisting cardiovascular and respiratory disorders, with the elderly, very young, poor, and ill being disproportionately affected (McMichael 1996).

In a normal year, about 175 Americans succumb to the demands of summer heat. An estimated 20,000 people were killed in the United States from 1936 through 1975 by the effects of heat and solar radiation (NOAA 2001).

4.1.1 Danger Zones

California was one of the states in the western region that showed the most extreme rise in frequency of high heat stress events and heat waves from 1949 to 1995 (NOAA 1999). A study by the National Oceanic and Atmospheric Administration (NOAA) analyzed weather data for trends in heat index and frequency in heat waves in U.S. cities. Researchers found that heat stress in cities across the country (represented by 113 U.S. weather stations) has increased dramatically over the past 50 years. They computed 1949–1995 trends in the frequency of extreme heat stress for each of 113 stations with complete data records. Both single-day events and multi-day heat waves were considered. Trends were upward over most of the United States. Trends in nighttime extremes were generally larger than for daytime, consistent with trends in mean conditions. The data are available on NOAA's Air Resources Laboratory website (www.arl.noaa.gov/ss/climate).

Data revealed an expected pattern in which summertime heat is more severe in the southeast and south-central United States and in the desert southwest.

All regions of the country showed slight upward trends in both heat stress days and nights and in the frequency of heat waves (PSR 2000, figures). San Francisco topped the list of cities, with 49 heat waves during the 1990s. Arcata ranked sixth, with 36 heat waves, and Los Angeles had 29. Other cities, such as Fresno, Sacramento, and San Diego showed no distinct upward trend (PSR 2000). Figures 5.1, 5.2, and 5.3 of the Environmental Defense Fund (EDF) report *Hot Prospects: The Potential Impacts of Global Warming on Los Angeles and the Southland* (Bloomfield et al. 2001) show the Los Angeles area currently and in the future. Using model projections and current trend analyses, the illustrations show the number of days that the temperature is greater than 90°F per year (EDF Figure 5.1), the projected number of heat waves per year (EDF Figure 5.2), and the maximum duration of heat waves in number of days (EDF Figure 5.3). All figures indicate increasing trends (NOAA 1999).

In 1998, Gaffen and Ross compiled temperature data for U.S. weather stations from 1948–1995. They found that "upward trends in the frequency of heatwaves are highly significant ($P < 0.01$) in the eastern and western regions [of the United States] and indicate an increase of about 20% in the number of heatwaves over the period from 1949 to 1995." (Gaffen and Ross 1998).

4.1.2 Heat Index

A body's natural cooling mechanisms are compromised more quickly when both temperature and humidity are elevated. *Heat index* is a unit of measure that combines temperature and humidity, and thereby more closely reflects what a human body experiences. Heat index is commonly used to describe projected changes in temperature and humidity that could occur with climate change.

For a current U.S. heat index map, see: www.weatherroom.com/map/usht.html.

For projections of U.S. heat index, see:
www.usgcrp.gov/usgcrp/nacc/background/scenarios/found/fig14.html.

Substantial increases in heat index, temperature, and precipitation are projected for California and Nevada. These projected changes can be seen at www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewlooking.htm.

4.1.3 Urban Heat Islands[1]

Global warming is expected to increase both heat and humidity, aggravating the effect of heat islands and increasing heat stress on urban populations (Kattenberg, Giorgi F. et al. 1996). Urban nighttime heat retention can be a factor in the greater number of heat-related deaths in urban areas, as compared to those in rural areas (Buechley, Van Bruggen et al. 1972). Also, during heat waves, when stagnant atmospheric conditions may persist, air pollution often compounds the effects of hot temperatures (FEMA 2003).

A recent study in the journal *Nature* (Kalnay and Cai 2003) estimates a mean surface warming due to urban sprawl and land use change to be 0.27°C (0.49°F) for the continental United States. Urban areas may therefore experience compounded problems of global warming and localized warming effects of the heat island effect.

4.1.4 Regional Variations

Heat waves have different impacts in different parts of the country, and have greater impact upon populations that are not adapted to such extreme conditions. Heat-related deaths in warm cities like Atlanta and Los Angeles, for example, would be lower than those in Philadelphia or New York (Kalkstein and Greene 1997). The California region currently has a lower risk of heat stress mortality than Midwest and Northeastern cities. In San Francisco and Los Angeles, winter mortality is projected to decrease; while in Los Angeles, summer mortality would increase. The estimated net change in mortality across

[1] An *urban heat island* is an urban area that generates and retains heat as a result of buildings, human and industrial activities, and other factors.

the nine large western cities examined in the National Assessment study is close to zero (National Assessment 2001).

4.1.5 Heat-related Health Outcomes

Global climate change will have direct impacts on human health, including increased mortality due to heat stress and heat waves (Dessai 2002). Nationally, heat waves are more deadly natural disasters than hurricanes, floods, or tornadoes (NOAA 2000). In 1999, for example, there were 497 heat-related deaths, compared to 92 deaths from tornadoes (NOAA 2000). Episodes of extremely hot or cold temperatures are associated with increased mortality (Curriero, Heiner et al. 2002).

Bunyavanich et al. (2003) characterizes the health impacts of heat waves as follows: "Heat waves cause rash, syncope (fainting), cramps, exhaustion, and heat stroke. Heat stroke is the most serious outcome, and results from impaired body thermoregulation." Heat rash can lead to fevers above 104°F, tachycardia, mental status changes, and death. Heat waves are also associated with adverse reproductive effects, such as low sperm count due to long heat exposure, and neural tube defects due to maternal hyperthermia. Occupational exposure to heat can provide clues as to what could occur for the general population with increased incidence and duration of heat waves projected as a result of climate change. For example, delayed conception as a result of occupational exposure has been observed. Some studies have also indicated that heat stress may induce some degree of blood hyper-coagulability (Kilbourne, Choi et al. 1982). During a heat wave, the increase in mortality is paralleled by an increase in morbidity (hospital and emergency room (ER) admissions), and in urban areas, the rate of heat stroke is higher in areas of low socioeconomic status (SES).

A Canadian study found that heat-related excess mortality occurred as low as the 30°C–35°C humidex[2] range, and that during a hot summer, 32 excess deaths would be expected; whereas, 34 fewer deaths would be expected during a cool summer (Smoyer-Tomic and Rainham 2001). Another study, conducted by the Centers for Disease Control and Prevention (CDC), found that during 1978–1998 in Los Angeles County, the age-adjusted, heat-related mortality was 44% lower than that in the general population (CDC 2001a)

But future higher temperatures and increased frequency of heat waves may increase the number of heat-related illnesses. The U.S. Environmental Protection Agency (EPA) estimates that a 3°F warming could almost double the heat-related deaths in Los Angeles, from 70 (in 1997) to 125 (although increased air conditioning use may not have been fully accounted for) (USEPA 1997). Little change in winter mortality is expected (USEPA 1997).

An Environmental Defense Fund (EDF) report (Bloomfield et al. 2001, Table 5.1) estimates the total excess mortality for three climate change models, assuming full acclimation, for

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[2] *Humidex* is a heat-stress index used in Canada that incorporates both temperature and humidity into one number, similar to the *heat index* used in the United States.

an average summer season. The heat-related mortality in Los Angeles for example, would increase by 62% to 88% of current levels under Global Climate Model (GCM) scenarios. It is noteworthy to mention, however, that these figures probably underestimate mortality, because full acclimation is assumed. It would be unlikely for people to adjust to the greater heat quickly enough. Buildings that house urban poor, in particular, might not be adequately upgraded in a timely fashion.

Excess heat-related deaths may somewhat be offset by a morbidity and mortality decrease, due to fewer extreme cold events in winter. Currently, in Los Angeles, the total excess mortality for an average winter season is 100 deaths, assuming full acclimation. According to Kalkstein and Greene (1997), that number could be reduced by 12%–23% by 2050.

4.1.6 Vulnerable Populations

If climate change increases the frequency and intensity of heat waves, rates of death and serious illnesses will increase—particularly in people that are most vulnerable to heat. These include children, the elderly, workers in hot industries, people of low SES, people with compromised immune systems, and people on medications such as anticholinergics and neuroleptics. Also, because men sweat more than women, men are more susceptible to heat illness, because they become more quickly dehydrated (Bunyavanich, Landrigan et al. 2003). Study results have shown that in Los Angeles, men were more likely than women to die from exposure to excessive heat (CDC 2001a).

According to the report, *Changing Habits, Changing Climate,* children will be among the most susceptible to more severe heat waves (CICH 2001). For example, children are less able to control their local climate than adults are, especially if a heat wave is sudden and severe (Bunyavanich, Landrigan et al. 2003).

According to the IPCC, heat-related deaths affect people of color twice as much as whites, and are projected to increase in Los Angeles from 68 in 1997 to 93 by 2020, and 118 by 2050 (IPCC 2001). In St. Louis, non-whites were twice as likely to die as a result of heat waves as whites (Miller and Brown 2000). Another study found that Los Angeles residents older than 65 years were more likely than those younger than 65 years to die from excessive heat. and blacks were more likely than whites to die from exposure of excessive heat, but the rate ratio was smaller than in the general U.S. population (CDC 2001a).

People with heart problems are also vulnerable because one's cardiovascular system must work harder to keep the body cool during hot weather. Heat exhaustion and some respiratory problems increase (USEPA 1997).

4.1.7 Adaptation

Increased temperatures may also result in more heat waves affecting hundreds of people, particularly young children and the elderly. Heat health watch and early warning systems are needed to provide advanced warnings of dangerously hot weather. Interventions should be more efficient (for example, use air conditioning instead of fans), and hospitals and nursing homes would need cooling systems to protect elderly and vulnerable patients from the effects of heat waves.

Climate warming could increase energy demand, such as air conditioning, water pumping, and cooling operations while reducing energy supply. According to the EPA, 10%–30% gains in energy efficiency are feasible through conservation measures, developing new (and using available) technologies, and better land management practices (USEPA 1997).

Research Needs

1. Extreme heat may be one of the most underrated of the deadly weather phenomena, and timely warnings are of utmost importance to provide necessary information for developing mitigation actions (Kalkstein and Greene 1997).
2. More information is needed about which weather parameters are important in the relationship between weather and health. Maximum temperature, minimum temperature, relative humidity, heat index, and duration of exposure are currently used to estimate exposure to heat. Further research into determining the importance of each of these factors will improve estimation of the relationship between heat and health and facilitate precautionary measures as the thresholds of the key parameters are reached.
3. More information is also needed about the association between heat and morbidity. Most susceptible are patients with certain chronic medical conditions: cardiovascular and cerebrovascular diseases, diabetes, respiratory and renal diseases, Parkinson's disease, Alzheimer's disease, and epilepsy (McGeehin and Mirabelli 2001). Individuals who lack social networks pose a particular challenge for prevention efforts. The feasibility and effectiveness of specialized health education efforts aimed at reaching these populations should be evaluated.
4. To improve the comparability of data collected during and following periods of extreme heat, methods of recording heat-related health outcomes should be standardized. Following the 1995 heat wave in Chicago, the Centers for Disease Control and Prevention (CDC) recommended the use of uniform criteria for the diagnosis of heat-related death. Since that recommendation, Donoghue et al. published diagnostic guidelines and criteria for use by medical examiners (Donoghue, Graham et al. 1997).
5. To assist the efforts of municipalities in their heat wave response plans, a greater understanding is needed of the importance of urban design to heat. Although some types of buildings (e.g., brownstones, tall apartment buildings) retain heat efficiently, other urban characteristics (e.g., tree cover, light-colored roofs) may facilitate wind, shade, and other heat-relieving conditions. Research and subsequent incorporation of these infrastructure characteristics into urban areas may contribute to a reduction of

the urban heat island effect and its associated health effects (McGeehin and Mirabelli 2001).

6. Assessing net annual health impacts, comparing both summer and winter mortality projections under climate change scenarios.
7. Although some locations in California appear to be less vulnerable to heat compared with the national average, it is unknown whether or not a threshold temperature exists, above which Californians may suffer adversely.

4.2 Wildfires

Together, heat waves and wildfires could cause firestorms with fatalities and injuries such as in the Los Angeles area in 1993, and in the Oakland-Berkeley hills in 1991. More recently, the Southern California wildfires of 2003 resulted in at least 20 fatalities, destroyed more than 3,400 homes, and burned more than 750,000 acres (Harvard Medical School 2003). Climate change could exacerbate the problem of wildfires, which can impact human health directly by causing fire-related injuries and death, as well as indirectly by affecting air quality and causing psychological stress.

4.2.1 California's Ecosystems

Wildfires are common in the hills throughout California and in the coastal communities of Southern California. Fire has always been a part of the area's chaparral and grassland ecosystems, as well as in other portions of California's complex landscape. The statistical models used to forecast fires in the desert grass- and shrub-land areas put the most weight on moisture anomalies occurring a year before the fire season: if the area has received greater-than-average moisture during the preceding year, a greater burn area is forecast. Conversely, models for higher elevations that contain heavier fuels (such as forest lands) put the greatest weight on the most recent moisture anomalies: if the area has received greater than average moisture recently, a lesser burn area is forecast. California receives a higher percentage of annual precipitation in March (on average) than is true elsewhere in the West, meaning that forecasts for higher elevations cannot be made until April, which may be too late for some uses, such as early requests for supplemental resources for fire fighting (Westerling, Gershunov et al. 2003).

Modeling results showed that the most severe effects of global climate change would occur in the Sierra foothills, where the predicted number of potentially catastrophic fires increased by 143% in grassland and 121% in chaparral (Torn, Mills et al. 1998). The same study showed that greater burn intensity resulted from a predicted change in fuel moisture and wind speeds. The fastest spread rates occur in grasslands, which is also where the biggest impacts are anticipated to occur. That study also showed that, under a climate change and over all vegetation types, the Santa Clara and Amador-El Dorado areas are expected to have more fast fires and fewer slow ones (Torn et al. 1998).

4.2.2 Conditions Conducive to Fires

Conditions that are more conducive to fires can occur with hotter and drier summers and a greater amount of vegetation resulting from wetter winters. It is predicted that on the whole, summers will become hotter, last longer, and dry out the vegetation and the soil more than they do now. The risk of fire may also increase with variations in rainfall due to El Niño-type events, whether it gets wetter or drier, because vegetation tends to build up during wet years. This build-up becomes additional fuel to be consumed by large fires during dry years. In addition, the increase in population and the continued development expansion into forested areas that are dominated by flammable vegetation creates a wildland/urban interface. The 1991 Oakland/Berkeley Tunnel fire was a poignant example of the massive damage potential of a fire in this interface. Developing homes in wild areas is common throughout California.

Plant pests and pathogens can also raise the risk of fire by increasing the number of dead trees in an area. In some areas of Southern California, infestations of the Western bark beetle have killed up to 80% of the pine trees. The pine trees' natural defenses may have been weakened by rising temperatures and prolonged droughts (Harvard Medical School 2003).

Southern California has historically suffered the largest fires in the autumn, when Santa Ana winds can develop with high temperatures (conditions are characterized by low relative humidity, high temperatures, and strong northeasterly winds), and during extreme heat waves throughout the fire season, when vegetation is highly flammable (Davis and Michaelsen 1995).

4.2.3 Frequency and Intensity of Fires

A changing climate may exacerbate conditions that lead to fires and affect their intensity and frequency. The risk of wildfires may increase by increasing wind speed and dry vegetation. As mentioned earlier, models showed that the faster, hotter fires burned more acres under a changed climate than under the current one (National Assessment 2001). In central, coastal California, one study predicted that the total area burned would increase, and that for temperature rises between 2°F and 8°F, fire intervals would decrease significantly (Davis and Michaelsen 1995). The study also pointed out, however, that spring precipitation would offset some of the projected increase.

As temperatures continue to rise, so will evapotranspiration, which could lead to more drying and more fires. Whether precipitation increases or decreases in the region, studies suggest that climate change will increase the risk of fire frequency. Forests with massive fuel buildup are predisposed to incontrollable crown fires. Warmer and drier conditions could lead to a dramatic increase in land area burnt and potentially catastrophic fires in California. Both the Hadley Climate Centre and Canadian Climate Center model scenarios yielded a 10% increase in the fire severity rating in the West (National Assessment 2001).

4.2.4 El Niño-Type Events and Santa Ana Winds

Other potential impacts of global warming include increased intensity of El Niño events and dry Santa Ana winds, which have dramatic impacts on the state (Timmermann 1999). Some global warming models project more frequent El Niño-type conditions and more winters with heavy downpours. As the Pacific Ocean temperature increases, the frequency and intensity of weather events such as El Niño will likely increase accordingly. In addition, other weather events like the drying Santa Ana winds will become more common. Combined with a warm summer, these drying winds will increase the chances of large wildfires, such as the Oakland/Berkeley Tunnel fire of 1991, which cost $2 billion in damages (Fried et al. 2004).

4.2.5 Losses Due to Wildfires

Wildfires are among the most pervasive of all the natural disasters, especially for California. According to the Insurance Services Office, of the 38 costliest U.S. wildfires between 1825 and 1995, 22 were in California, which ranks number 1 in economic losses due to wildfire (LBNL 1999). Increases in California wildfires will most likely result in serious consequences for the residents and their property.

4.2.6 Public Health Impacts

Public health impacts include obvious impacts such as physical harm (people dying in a fire, burns, and smoke inhalation), as well as secondary or indirect effects; fire for example could decrease water quality (sediment runoff) and add to air pollution. Fire smoke carries a large amount of fine particles that exacerbate cardiac or respiratory problems, such as asthma and chronic obstructive pulmonary disease (Duclos, Sanderson et al. 1990).

4.2.7 Secondary Events

Global warming models project more frequent El Niño-type conditions and more winters with heavy downpours (Bloomfield, Koteen et al. 2001). Post-fire events such as landslides, flooding, debris flows, and water quality impairment could worsen under climate change, should the intensity and amount of winter precipitation increase (IPCC 2001), and can all impose additional costs (Torn, Mills et al. 1998).

4.2.8 Regional Variations

In terms of wildfires, it seems that densely populated areas are less impacted by climate change than sparsely populated areas. Rural areas with fewer fire suppression resources are also at a greater risk of being subject to climate-change-related fires (Davis and Michaelsen 1995).

Table 1 shows that densely populated areas (which likely have more fire-suppression resources available) would be less affected by a changing climate than the more sparsely populated areas, under a projected doubling of CO_2 (Torn, Mills et al. 1998).

Table 1. Annual fire outcomes under present and future (double CO_2) climate. Effect of population density.

	Number of Escaped Fires			Acres Burned by Contained Fires		
	Present	Future	Change	Present	Future	Change
Santa Clara, Grass						
Low Population	2.6	4.7	80%	12.0	16.0	33%
Moderate Population	1.9	2.2	16%	16.4	24.8	52%
Amador – El Dorado, Chaparral						
Low Population	2.4	8.2	242%	5.9	15.5	161%
High Population	2.6	2.9	11%	1.3	2.1	65%

Source: Torn et al. 1998.

4.2.9 Vulnerable Populations

Low-income and minority households are less likely to have access to healthcare; minorities are twice as likely to be uninsured as whites; and poor and near-poor adults are six to seven times as likely to be uninsured as higher-income adults (Miller and Brown 2000). Yet, fire does have impacts that cut across SES.

4.2.10 Adaptation

Massive damage potential of a fire exists in the wildland/urban interface; however, the effectiveness of heightened suppression intensity shown in Table 1, where densely populated areas (where more lives and property are at stake) would be less affected by a changing climate than more sparsely populated areas, may be an example of a successful adaptation strategy.

Fire prevention methods include: prescribed burning, which is strategic placement of prescription burns that helps to ensure the most efficient fire hazard reduction and to minimize the amount of landscape exposed to unnaturally high fire frequency (Keeley

2002); mapping fire behavior; limiting development in high fire-hazard areas; improving access for emergency and evacuation vehicles; increasing fire-resistant structures, and increasing public education (International Association of Fire Chiefs and Western Fire Chiefs Association 1996).

Research Needs

1. Knowledge of how climate change will affect plant pathogens and pests (which can affect the risk of fire) is a major research gap. Climate forecasts need to be improved, as does the understanding of the state's vulnerability to wildfires. For further recommendations, see the next section.
2. Smoke from wildfires can affect air quality. With more fires likely under a changed climate, the contribution of fires to health effects from compromised air quality for Californians would be an important area for further research.
3. More studies are needed on morbidity from woodland fires (Greenough, McGeehin et al. 2001).
4. Because wildfires can have serious consequences for health, further research is needed to assess wildfire risks under a changed climate; particularly the effect of climate change on Santa Ana winds, winter precipitation, and peak summer temperatures.

4.3 Extreme Events

4.3.1 Global Warming Impacts

Under precipitation projections for the decade of 2040 to 2049, extreme events rose from 0.1% of wet days per year to 1% under climatic change (NASA 2003). Such is the projection for all major basins in California. By the year 2100, temperatures in California could rise by about 5°F, precipitation could increase by 20%–30%, and sea level could rise 13 to 19 inches if warming goes unchecked, according to the EPA and the IPCC (USEPA 1997; IPCC 2001).

4.3.2 Heavy Precipitation and Flooding

Modeling has shown that increasing CO_2 levels in the atmosphere may lead to a rise in the number of annual extreme precipitation events in the Sierra Nevada mountains, which in turn could increase the frequency of flooding in California (NASA 2003). The Sierra Nevada region may experience substantial increases in heavy precipitation (> 2 inches of rain/day), and extreme precipitation events (> 4 inches of rain/day) (NASA 2003). Most of these increases would occur during the winter, currently the wettest season in the region. Heavy precipitation events could increase by 10 to 15 days per year; whereas, extreme events could increase by 5 to 10 days/year (NASA 2003).

Modeling has also shown that the mountain elevation level at which freezing occurs will rise with temperature, which means that much of the precipitation that historically fell as snow will instead come in the form of rain. These changes could lead to a greater frequency of flooding (Boesch, Field et al. 2000). Another NASA study finds that climate warming over the next century will bring potential flooding in winter, as a result of increased stream flow throughout California. The study also finds less water would be available during the summer months (NASA 2002).

Increased winter flows to San Francisco Bay could increase the risk of flooding. The fragile environment of the bay's delta islands could be at risk from increased flooding and the upstream movement of saltwater from the bay (National Assessment 2001).

Besides the immediate harm that floods cause such as drowning, hypothermia and trauma, other related problems include fires from broken gas lines and oil tanks; toxic waste from overflow of waste treatment plants, and even snake bites (see Section 4.7.5). Infections, such as shigellosis, salmonella, hepatitis A, typhoid, and diarrhea due to *E. coli* can also spread through dirty water and sanitation runoff (Zibulewsky 2001).

4.3.3 Landslides

Wet weather is a root cause of landslides. California has certain land forms that are especially susceptible to landslides—most visibly the coastal bluffs and mountains. In some cases, human-caused fires, erosion, and vegetation changes make landslides more likely to occur (NOAA 2000).

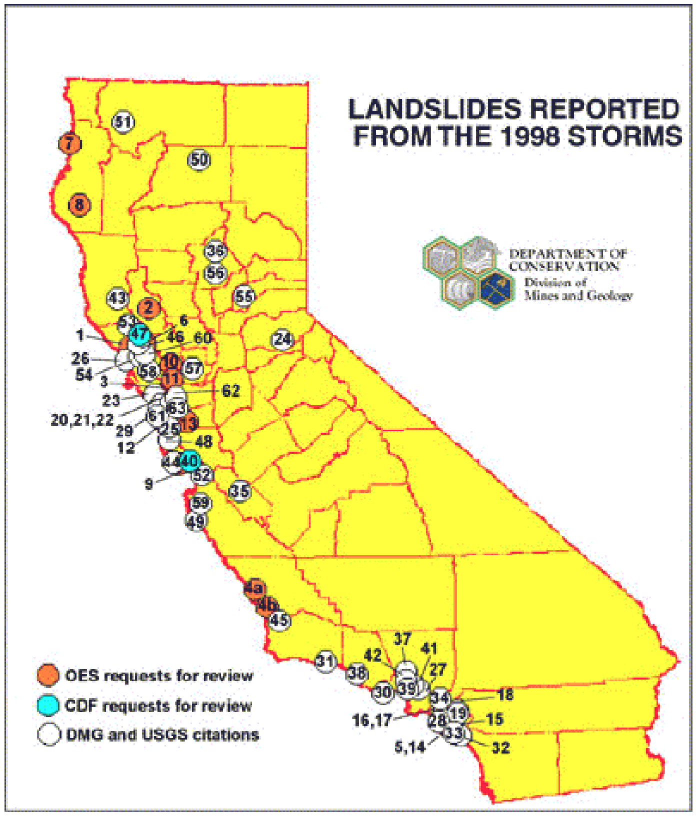
Following extreme events such as hurricanes and tornadoes, injuries can also occur from the broken glass or debris, collapse of houses, and by mudslides. For example, Figure 1 displays the landslides that were reported in California following the 1998 storms.

Wildfires can cause conditions that facilitate erosion and flooding. Figure 2 illustrates drainages that were subject to flooding and/or debris flows as a result of the 1997 Baker fire in Orange County.

4.3.4 Droughts

According to FEMA, with respect to heat wave danger zones, all areas in the United States are at risk of drought at any time of the year. Drought gripped much of the West and Midwest from 1987 to 1991. The Missouri River Basin and California have experienced extended periods of drought as well (FEMA 2003).

More information on California's droughts is available at the California Applications Program's (CAP's) website entitled "Drought grips western US," available at: http://meteora.ucsd.edu/cap/western_drought.html.



OES=Office of Emergency Services
CDF=California Department of Forestry and Fire Protection
Source: http://anaheim-landslide.com/landslide98.htm (1998 Landslide Inventory. California Department of Conservation, Division of Mines and Geology)

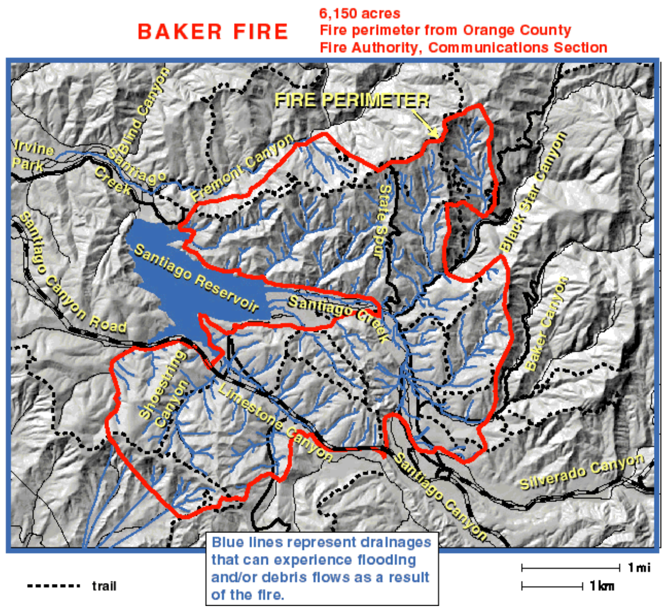
Figure 1. Landslides in California reported from 1998 storms

4.3.5 Sea Level Rise

Sea level rise can lead to sewage disposal disruption, salinity of freshwater aquifers, and even immigration. Sea level is expected to rise by at least one foot over the next few decades, which will affect mostly seaside communities. An increase in storm wave height is also anticipated along with the threat of severe shoreline erosion (National Assessment 2001).

4.3.6 Post Traumatic Stress Disorder (PTSD)

The occurrence of extreme events may also impact affected individuals' emotional or mental health. Depending on the severity and nature of the weather event, people may experience disabling fear or extreme aversion. There is controversy about the incidence



Source: http://landslides.usgs.gov/html_files/landslides/scfires/baker.html

Figure 2. Potential flooding and landslide areas following the 1997 Baker fire

and continuation of significant mental problems, such as post traumatic stress disorder (PTSD), following disasters. However, an increase in the number of mental disorders has been observed following several natural disasters in the United States. Increased mental problems were described during the five-year period after Hurricane Agnes caused widespread flooding in Pennsylvania in 1972. More recently, a longitudinal study of local residents who lived through Hurricane Andrew showed that 20%–30% of adults in the area met criteria for PTSD at six months and two years after the event (Greenough, McGeehin et al. 2001).

4.3.7 Vulnerable Populations

The impact of extreme events will more likely be greater for minorities and people of lower SES. Minority households are less likely to be insured as whites; low-income adults are 6 to 7 times as likely to be uninsured as higher-income adults (Miller and Brown 2000).

4.3.8 Adaptation

Workable floodplain management, with mitigation incentives to reduce losses from floods, should take precedence over unplanned development. This action, coupled with restoring environmentally sensitive coastal land and critical estuarial and riverine habitats or converting other areas to recreational uses, should minimize death and injury from flooding and hurricane storm surges. Mitigation policies should be established in areas not yet developed. The roles of disaster response agencies and relief organizations need to be better defined, and coordination among local fire, public health, emergency medical services (EMS), police, and relief agencies must be improved.

Public education is critical. The Federal Emergency Management Agency (FEMA) recommends the establishment of a National Hurricane Program, commissioned to minimize loss from hurricanes through training and education, especially in the areas of warning, evacuation procedures, and property protection (Greenough, McGeehin et al. 2001). Improved building engineering codes and zoning are key adaptations that can reduce vulnerability.

Public Health Disaster Planning

Disasters disrupt the infrastructure, thereby seriously impacting medical transportation, sanitation, housing, communications, and electricity. Health problems occur at varying times during a disaster. Keeley et al. (1999) found that the most significant problem in a disaster recovery effort was communication-related. However, disasters with sufficient warnings and planning can result in fewer injuries and deaths.

Disasters do more than cause unexpected injuries and deaths. Among their effects are the destruction of healthcare infrastructure and environmental impact (Zibulewsky 2001). Disaster response consists of three phases: activation, implementation, and recovery (Zibulewsky 2001).

Contingency Plans. To be effective, disaster planning should include: a headquarters recovery team; a protected and backed up information system; back-up and alternative systems for health care centers, water, power, and sanitation; and a communications recovery team to deal with severed phone lines. Storm water pollution must be controlled to reduce risk of flooding exacerbated by urbanization (Swamikannu, Radulescu et al. 2003). Anticipating a fire's actions or establishing pre-planned escape routes and safety zones are required (Hatlestad 2002). In short, a well-planned system includes headquarters, computer system, utilities, and communication (Pope 1994a).

Resource Management. Resource management is key to disaster preparedness and response. The type of disaster, the resources of the affected community and those of neighboring communities, and the community's vulnerability all determine what supplies will be needed in a disaster. Immediate needs fall within the medical sector (Pesik and Keim 2002).

Research Needs

1. Improved climate models at temporal and spatial scales useful for projecting trends in regional extreme events will help mitigation and preparedness.
2. In addition, national and regional health data collection beyond the direct impacts of a disaster will help in health program planning. Examples include information on the kind of response activity undertaken, the resources made available for relief and recovery, and long-term health effects such as PTSD. Databases should utilize standardized definitions and outputs. To fully understand climate-driven health

impacts, we need long time-series of compatible data from integrated monitoring programs.

3. Insurance companies and departments of commerce are looking at risk analysis and predictors of mortality, such as geographical topography, stream flow velocities, and coastal/floodplain development.
4. Flow studies are needed that delineate toxic releases into water supplies and their potential health effects. The technology to map out the entire state to determine risk areas—population densities in flood plains and coastal areas, areas of landslide risk, and areas of deforestation—could be used for that purpose.
5. Comprehensive epidemiologic studies can better guide mitigation efforts. Future studies on floods, for instance, should elucidate the relationship of extreme events and morbidity and mortality rather than looking only at the individual event. To date, few epidemiologic studies have examined the public health effects of flooding or evaluated the benefits of effective mitigation strategies.

4.4 Air Quality

There is already extensive evidence on the health effects of air pollution. Ground-level ozone can exacerbate chronic respiratory diseases and cause short-term reductions in lung function. Exposure to particulate matter can aggravate chronic respiratory and cardiovascular diseases, alter host defenses, damage lung tissue, lead to premature death, and possibly contribute to cancer. Climate change may affect air quality by affecting weather, anthropogenic emissions, and biogenic emissions, and by changing the distribution and types of airborne allergens Local temperature, precipitation, clouds, atmospheric water vapor, wind speed, and wind direction influence atmospheric chemical processes, and interactions occur between local and global-scale environments (Bernard, Samet et al. 2001).

Parts of California already have bad air quality, and most counties have higher pollution levels than those acceptable by California regulatory agencies. In effect, 28 of the state's 58 counties failed to meet standards for air quality (ALA 2003a), and 33 million of the state's 35 million people are breathing dirty air. That number is up by nearly four million people since 2002. In addition, the nation's four smoggiest urban areas were all in California. Having six metropolitan areas listed among the 10 highest ozone areas of the nation makes California the smoggiest state in the nation—with Southern California being the worst-off—not even accounting for particulate matter (PM), which is considered even more dangerous than smog (ALA 2003b).

California's South Coast Air Quality Management District provides a summary of health effects studies (AQMD 1996). Cars and trucks are California's primary sources of air pollution, emitting ozone (O_3), carbon monoxide (CO), CO_2, oxides of nitrogen (NO_X), PM, and other harmful substances. California has over 26 million vehicles on its roads, and the increasing popularity of trucks and SUVs (that produce 1.5 to 2.5 times the emissions of passenger cars) further contribute to the state's problems (CEC 1989). In the Los Angeles area, population density, motor vehicles, climate, and geography conspire to create some of the nation's worst air quality. Bakersfield and Fresno are also struggling with severe air quality problems, as is the San Joaquin valley. As a result, Sequoia National Park has suffered the consequences of having the worst smog of any national park and more days of unhealthy ozone than Los Angeles and New York City combined (Associated Press 2001).

4.4.1 Ozone

Ozone is already a critical problem in California. The Los Angeles South Coast Air Basin is the only area in the country given an "extreme" rating for O_3 concentration by the EPA. The Southeast desert, Sacramento, San Joaquin Valley, and Ventura regions are rated "severe." The East Kern County, San Diego, and Santa Barbara areas are rated "serious" (USEPA 2003).

Higher air temperatures can increase the concentration of ozone at ground level, especially during stagnant wind conditions. The natural layer of ozone in the upper atmosphere blocks harmful ultraviolet radiation from reaching the Earth's surface; but in the lower atmosphere, ozone is a harmful pollutant. Ozone damages lung tissue, and causes particular problems for people with asthma and other lung diseases. Even modest exposure to ozone may encourage the development of asthma in children (McConnell, Berhane et al. 2002). The American Lung Association reports that in 2003, more than half a million children in California were at risk for asthma, as were more than 1.7 million adults in the state (ALA 2003c). In much of the nation, a warming of 4°F could increase ozone concentrations by about 5% (USEPA 1997).

Higher temperatures increase ozone formation when precursors are present. Should wetter conditions increase biomass, which emits ozone precursors, air quality could deteriorate (National Assessment 2001). Ozone and non-volatile secondary PM will generally increase at higher temperature, due to increased gas-phase reaction rates (Aw and Kleeman 2003). Interannual temperature variability can change peak O_3 and 24-hr average $PM_{2.5}$ by 16% and 25%, respectively, when other meteorological variables and emissions patterns are held constant (Aw and Kleeman 2003).

Two major phenomena appear to lead to high O_3 in the San Joaquin Valley (SJV): Transport of O_3 and precursors from upwind areas (primarily the San Francisco Bay Area, but also the Sacramento Valley) into the SJV, affecting the northern part of the valley. Emissions of precursors, mixing, transport (including long-range transport), and atmospheric reactions within the SJV are responsible for regional and urban-scale (e.g., downwind of Fresno and Bakersfield) distributions of O_3 (Pun, Louis et al. 2000). The San Joaquin Valley has overtaken Los Angeles as the smoggiest region of the country.

Volatile Organic Compounds (VOCs) and oxides of nitrogen (NO_X) are precursors of ozone and are emitted from a variety of human and natural sources. In California, the biggest source of both emissions are from vehicles. Plant species responsible for biogenic VOC emissions of isoprene and monoterpenes vary by region of the country and include oak, citrus, eucalyptus, and pine in the Southwestern United States (Bernard, Samet, et al. 2001).

Plant species responsible for biogenic VOC emissions of isoprene and monoterpenes vary by region of the country and include oak, citrus, eucalyptus, and pine in the Southwestern United States (Guenther 2000) Isoprenes are an important biogenic volatile organic compounds (VOCs) especially emitted by woody plants. Isoprene production is controlled primarily by leaf temperature and light (Guenther 2002). Biogenic VOC emissions are so sensitive to temperature that an increase of as little as 2°C could cause a 25% increase in emissions (Guenther 2002) .

Ozone exposure may reduce the rate of lung growth during childhood and accelerate the decline of lung function during adulthood. Exposure to O_3 for several hours can cause respiratory distress in as many as 20% of healthy adults and children, while prolonged exposure can cause irreparable lung damage (CEC 1989). One prospective cohort study of children and adults in Southern California showed that exposure to high levels of O_3 was associated with an increased decline in lung function. Another recent study of children in Los Angeles found lower lung function associated with peak O_3 exposure, particularly among children reported to spend more time outdoors (Bernard, Samet et al. 2001).

Bloomfield et al. (2001, Figure 5.4) portrays the increasing trend in ozone peak concentrations in the Los Angeles Basin under both controlled emissions and climate change scenarios. The same report compares the changes in ozone concentration for controlled and non-controlled emissions scenarios using model simulations for increased temperature. (Bloomfield et al. 2001, Figure 5.5).

But even if ozone pollution is controlled in the United States, international transport of ozone precursors must be considered. Fiore et al. (2002) used a three-dimensional global model of tropospheric chemistry driven by assimilated meteorological observations to investigate the origin of this background and to quantify its contribution to total surface

O_3 on both average and highly polluted summer days. During the summer of 1995, background O_3 produced outside of the North American boundary layer contributed an average 25–35 parts per billion by volume (ppbv) to afternoon O_3 concentrations in surface air in the western United States.

4.4.2 Pollen and Allergens

It has been suggested that climate change will increase exposure to natural allergens. Climate change could shift the timing and distribution (and affect the allergenicity) of pollen, thereby affecting the occurrence and severity of asthma and allergic reactions. In effect, one of the most predictable effects of global warming is that CO_2 is going to increase and that seasonality is going to change. Trends such as earlier springs and longer growing seasons affect plants' biomass, making them larger at maturity and, logically, able to produce more pollen (Gehrman 2003), which may significantly increase exposure to allergenic pollen (Wayne, Foster et al. 2002). In fact, a doubling of the atmospheric CO_2 concentration stimulated ragweed-pollen production by 61% (Wayne, Foster et al. 2002).

In addition, higher allergenic content was found in samples collected from sites with higher daily mean temperature. Further research is needed to confirm results in other allergen-containing plants (Ahlholm, Helander et al. 1998).

The passing of major weather fronts and the associated temperature drops, wind disturbances and rainfall are the major factors influencing ragweed pollen counts according to Barnes et al., who showed in their study in 2000 that rain always lowered pollen counts and that pollen counts were highest at noon and lowest at 6:00 pm (Barnes, Pacheco et al. 2001).

For 2000 and 2001, average daily values of CO_2 and air temperature within an urban environment were 30% to 31% and 1.8°C to 2.0°C higher than those at a rural site. Ragweed grew faster, flowered earlier, and produced greater pollen at urban locations, relative to rural locations. Air temperature and atmospheric CO_2 (two aspects of future global environmental change) are already significantly higher in urban areas relative to rural areas (Ziska, Gebhard et al. 2003).

Fungi have adapted to virtually all environments, but fungal growth is often enhanced at increased temperature and/or humidity (Bernard, Samet et al. 2001). Although summers in California may be hotter and drier, with climate change depressing some kinds of fungal growth, increased aridity and eventual desertification may increase particulate-carried fungal spores (Bernard, Samet et al. 2001). This phenomenon is discussed further in the sections about coccidioidomycosis.

4.4.3 Particulate Matter

Air quality is a significant problem in many parts of the West. For example, with 17 million inhabitants occupying a basin subject to many temperature inversions, the greater Los Angeles area has a particularly serious problem with ground-level ozone levels and particulate matter. In addition, many western cities have particulate matter concentrations close to or exceeding federal standards (National Assessment 2001).

The EPA rates the following areas in California as "serious" for particulate matter (PM): the Los Angeles South Coast Air Basin, the San Joaquin Valley (SJV), the Coachella Valley, and Owens Valley (also in the SJV, dust storms increase the risk of Valley Fever, also known as *coccidioidomycosis*) (USEPA 2003). Fine particulate matter could increase under a changing climate, leading to further health problems. However, El Niño conditions (more storms and precipitation in the winter) would be likely to reduce levels of winter air pollutants such as CO and PM (National Assessment 2001).

There is consistent evidence that the levels of fine PM in the air are associated with the risk of death from all causes, and especially from cardiovascular and respiratory illnesses. This evidence strengthens the rationale for controlling the levels of respirable particles in outdoor air. Samet et al. (2000) conducted a study which revealed that each $10\mu/m^3$ increase in PM_{10} corresponded to a 0.51% increase in the relative rate of death from all causes, and a 0.68% increase in the relative rate of death from CV and respiratory diseases.

Nitrogen dioxide, CO, or particulate optical reflectance are strongly associated with daily mortality. They are also highly correlated with one another, making it impossible to discern each one's individual impact on the outcome (air pollution-related mortality). Study results show that small, but significant, associations exist in Los Angeles County between daily mortality and three separate environmental factors: temperature, vehicle-related pollutants , and photochemical oxidants (Kinney and Ozkaynak 1991).

4.4.4 Dust

Dust may serve as a medium for the global transport of microorganisms. The number of airborne microorganisms can be two to three times that found in clear atmospheric conditions, as documented through African dust events. Exposure to desert dust has been identified as the source of a number of public health threats (such as coccidioidomycosis in humans, silicosis, allergic reactions, and asthma), and can contaminate cisterns (Griffin, Garrison et al. 2001).

Asian dust has also made its way to the American West Coast. In 2001, the Death Valley, California was covered by a persistent haze. In a region where the skies are almost always crystal clear, visibility was limited to no more than 10 miles. The likely cause was dust, carried across the Pacific Ocean from the deserts of Asia (NASA 2001).

Airborne aerosols caused by humans used to be the main concern of scientists studying the effects of air pollution, and now there is growing concern that naturally occurring dust storms, such as those from Africa may pose health risks. Every year, Sahelian dust storms alone deposited an estimated at 500 million to more than 1 billion tons of dust. (Taylor 2002).

Dust storms contain an incredible mix of all kinds of aerosols that are not seen anywhere else. In China, many blame desertification for the increasing intensity of dust storms while others believe that long-term climate trends are to blame (Cyranoski 2003).

Also, increased aridity and eventual desertification from increasing temperatures may increase particulate-carried fungal spores, multiplying the potential for endemic and epidemic fungal infection. This phenomenon is documented most exclusively for cocci, which is spread by dust, and is often preceded by increased rain. A well-documented cocci outbreak followed the 1994 Northridge, California, earthquake. Much dust was disseminated, which increased the risk for cocci. Global warming and population growth in arid areas such as the U.S. Southwest are likely to increase the risk of such hazards (Patz et al. 2000). Large dust events have been reported to affect approximately 30% of the U.S. landmass (Griffin, Garrison et al. 2001).

4.4.5 Ozone Depletion and UV Radiation: Potential Link to Climate Change?

The causal link between squamous cell carcinoma and cumulative solar exposure has been well established. Sunbathing is a widespread activity for South Californians. In addition, ultraviolet (UV) exposure at a very young age is more detrimental than exposure in adulthood, and UV radiation is a definite risk for certain types of cataract. The possibility that the immune system response to vaccination could be depressed by UVB[3] exposure is of considerable concern (de Gruijl, Longstreth et al. 2003). A physical link between global warming and stratospheric ozone depletion also has been demonstrated in atmospheric models; this depletion results from the trapping of heat in the troposphere, thereby cooling the stratosphere and allowing further ice crystal formation that can enhance the ozone-depleting chemical reaction (Shindell, Rind et al. 1998).

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[3] *UVB* is ultraviolet radiation with wavelengths from 280–320 nanometers that has been associated with harmful health effects, such as skin cancer.

4.4.6 Asthma

Asthma is the most prevalent chronic disease among children in California—2.3 million Californians suffer from it, and the problem is growing (ALA 2002).

There is some recent evidence that ozone triggers and worsens asthma attacks. In fact, recent data from Gent et al. suggest that even at low levels of ambient ozone (and controlling for ambient fine particle concentration), children with severe asthma using maintenance medication are particularly vulnerable to O_3 and are at a significantly increased risk of experiencing respiratory symptoms (Gent, Triche et al. 2003). The researchers identified that O_3 was significantly associated with respiratory symptoms and rescue medication use among those using maintenance medications. A 50 ppb increase in O_3 corresponded to 35% of wheezing and 47% chest tightness (Gent, Triche et al. 2003).

It is also possible that ozone air pollution may actually lead to the development of asthma in children, in addition to simply exacerbating existing disease (McConnell, Berhane et al. 2002). Controlling for the level of activity in children playing after-school sports, the relative risk of developing asthma was 3.3 times higher in communities with high ozone than it was in low-ozone-polluted communities (McConnell, Berhane et al. 2002).

In Atlanta during the 1996 Olympic Games, air pollutants from vehicle emissions fell by about 30% (peak daily O_3 decreased 27.9%). Concomitantly, the number of acute asthma attacks fell by an estimated 40%, and pediatric emergency admissions dropped 19%. (Friedman, Powell et al. 2001).

4.4.7 Co-benefits of Greenhouse Gas Reduction

Greenhouse gas (GHG) mitigation can provide considerable local air pollution-related public health benefits by reducing fossil fuel combustion. Lessening fossil fuel emissions in accordance with the Kyoto Protocol over the next two decades could reduce PM and O_3 and avoid approximately 64,000 premature deaths, 65,000 chronic bronchitis cases, and 3 million person-days of work loss (Cifuentes, Borja-Aburto et al. 2001). Air pollution mapping for the South Coast Air Basin of California estimated that 1,600 lives would be saved if ambient air pollution standards were attained. (Cifuentes, Borja-Aburto et al. 2001).

4.4.8 Vulnerable Populations

Warmer temperatures may increase the rate of smog formation and exacerbate incidences of asthma. Low-income communities could be disproportionately impacted by adverse health impacts, due to minimal access to health care and higher exposure to smog in inner-city areas.

According to the report *Changing Habits, Changing Climate,* children will be among the most susceptible to more intense air pollution (CICH 2001). Childhood asthma and respiratory problems, already a major public health issue, may be aggravated if global warming leads to warmer and more stagnant conditions. The net effect of pollution is much greater for children of lower SES. Pollution is one mechanism through which SES affects health (Neidell 2001).

4.4.9 Adaptation

One step toward attaining ozone standards was attributed to California's Phase 2 Reformulated Gasoline (RFG), which was introduced in 1996. Studies of vehicle emissions and ambient air quality data have reported substantial reductions of O_3 precursors due to RFG. In fact, O_3 benefits attributed to California RFG are 8%–13% in the Los Angeles area, 2%–6% in the San Francisco Bay Area, and 3%–15% in the Sacramento area (Larsen 2001). Also, it was found that the announcement of health advisories decreased asthma hospitalizations by 4%–7% (Neidell 2001).

Other specific adaptation strategies include early warning systems, mass transit, and urban planning—as well as pollution control.

Research Needs

1. Improving understanding of the relationships between emissions of air pollutants, climate change, and resulting air pollution (National Assessment 2001)
2. Basic atmospheric science work on the association between weather and air pollutants, including boundary layer dynamics, urban heat island effects, and the contribution of transboundary pollution, dust, and/or precursors
3. Improving air pollution models and their linkage with climate change scenarios
4. Closing gaps in the understanding of exposure patterns and health effects
5. The balance should be addressed between heavy precipitation (as a tropospheric "cleansing" mechanism) versus heat-related or stagnant air mass exacerbation of pollution.
6. Needed are better emission scenarios, including both anthropogenic and vegetative emissions. How will changing energy demands effect emissions?
7. Another identifiable research gap pertains to the hypothesis of a link between stratospheric ozone and climate change, and that the ozone hole recovery could be slower under a changing climate.
8. Research on the combined effects of temperature and humidity on air pollution.

9. Research on the effect of weather on vegetative emissions and allergens such as pollen. Will more pollen be produced? Will there be a longer allergy season? Could a longer allergy season, run into summer high ozone pollution periods; have synergistic adverse effects?
10. Assessment of health risks that result from the use of technological adaptations that can increase air pollution (like air conditioner use, for example). Also, if new pesticides are used as an insect control measure, assessment of the effects of these pesticides on human health (USEPA 1997).
11. Current research has led to an improved understanding of the role of fine particulates in cardiovascular and lung disease. Further research is needed on the effects of climate on fine particulates.
12. A better understanding of the relationship between ozone and direct heat effects on mortality would be important for prioritizing interventions during heat waves.

4.5 Infectious Vectorborne Diseases

4.5.1 Encephalitis

In California, as in much of the world, there is concern that increased heat and moisture will facilitate the spread of emerging infectious diseases, many of which are vectorborne. West Nile virus (WNV), for example, was first documented in the United States in New York City, and was confirmed in California in 2002 (CDHS 1999). Data suggest that outbreaks of encephalitis exhibit large interannual variability and are associated with climate variables such as precipitation, PDSI, and temperature (CAP 2003).

Prior to WNV entering the United States, the arboviral disease most commonly causing human epidemics in the United States was St. Louis encephalitis (SLE). Other common diseases include: eastern equine encephalomyelitis (EEE), found in the eastern United States; La Crosse encephalitis (LAC), found from the Midwest to the Atlantic seaboard; and western equine encephalomyelitis (WEE), in the western half of the United States and parts of Canada and Mexico. Together, these viruses account for about 65% of encephalitis cases reported by etiology (Gubler, Reiter et al. 2001).

St. Louis encephalitis first occurred in the United States during the 1933 “dust bowl” and outbreaks have been associated with droughts. West Nile virus also tends to follow droughts and heat waves, as was the case both for the 1996 Romanian and 2000 Israeli outbreaks (Epstein 2001).

Retrospective analyses have shown that during cool wet El Niño years, WEE virus usually becomes active when vector abundance is high; whereas, SLE tends to appear during hot, dry La Niña years when hot summer temperatures facilitate transmission by reducing the extrinsic incubation period (Cayan, Tyree et al. 2003). Both WEE and SLE are caused by arboviruses. The activity of these viruses has increased in California over the last decade. Research shows a positive correlation between increased winter precipitation (or spring snow accumulation) and summer abundance of *Culex tarsalis* (a mosquito that carries the viruses that cause these diseases), meaning that prior season moisture indices may be useful predictors of summer mosquito abundance (see Figure 3) (Cayan, Tyree et al. 2003).

Because temperatures may increase or reduce survival rate, depending on the nature of the vector, the probability of transmission may or may not be increased by higher temperatures. Reeves et al. predicted that a 3°C–5°C increase in average temperature may cause a northern shift in the distribution of both WEE and SLE outbreaks and a decreased range of WEE in Southern California, based on temperature sensitivity of both virus and mosquito carrier (Reeves, Hardy et al. 1994). With global warming, epidemics of these diseases could extend into currently unreceptive northern areas. In 1994, Reeves et al. found that daily mortality of adult vectors increased by 1% for each 1°C increase in temperature. Also, a strong correlation between mosquito abundance and summertime has been identified (Cayan, Tyree et al. 2003).

In general, temperatures affect the rate and timing of biological functions; whereas, precipitation (water) affects population size (Reeves, Hardy et al. 1994). Warming temperatures increase the rate of biological functions, and therefore increase the rate of mosquito development from egg to adult, decrease population generation time, and increase population growth rate (Reisen 1995). Virus replication within the mosquito host also progresses faster at warmer temperatures, decreasing the time required from infection to transmission (Reisen, Meyer et al. 1993). Encephalitis viruses tend to be transmitted most effectively during warm summer months (Reisen 1995).

Wet years generally increase mosquito population size (through increase of suitable habitat) (Wegbreit and Reisen 2000). Urban *Culex* mosquitoes however may be most abundant during dry years, because they develop in storm water channels and water pools (which can result from failure to scour drainage systems during a dry year).

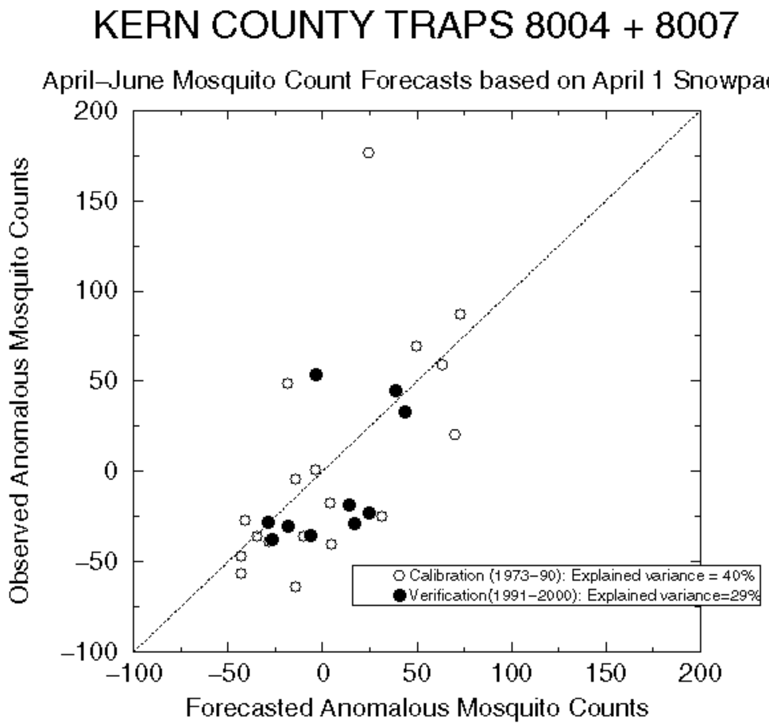

Figure 3. Comparison of observed and "forecasted" April–June female *Cx. tarsalis* counts, based on 1973–1990 linear regression with April 1 snow water content in Kern River watershed. *Cx. tarsalis* counts are averages from Kern MVCD traps 8004 and 8007.

Source: http://meteora.ucsd.edu/cap/mosq_climate.html (Cayan et al. 2003).

4.5.2 West Nile Virus

Following its explosive debut in New York City during the spring drought and heat wave of 1999, WNV spread across the nation in 2002, in the largest outbreak of mosquito-borne encephalitis in the western hemisphere (Epstein, Chivian et al. 2003). Some scientists speculate that drought conditions played a role.

Cx. tarsalis should be considered a potentially important vector of WNV in the western United States (Turell, O'Guinn et al. 2002). *Culex* species are likely to play the primary role in the enzootic maintenance and transmission of WNV in California (Goddard, Roth et al. 2002). Continued WNV activity was detected in mosquitoes, sentinel chickens, and wild birds (for the first time in California) in September of 2003. For more information, see: www.westnile.ca.gov (CDHS 2003c).

One theory about climate and WNV is that drought and hot conditions could lead to viral amplification between birds and mosquitoes. St. Louis encephalitis is a virus quite close in biology to WNV. Shaman et al. (2002) found that following extended spring droughts in Florida, sentinel chicken flocks became infected with St. Louis encephalitis virus (SLEV). Shaman et al. postulated that vector mosquitoes and nestling, juvenile, and adult wild birds congregate in selected refuges; this ecology would facilitate epizootic amplification of SLEV. Following the drought, SLEV-infected *Culex* mosquitoes and wild birds could disperse, initiating an SLEV transmission cycle. This scenario could be similar for WNV, considering anecdotal correlation between drought and epidemics (though it remains to be proven in the United States).

4.5.3 Lyme Disease

The California Department of Health Services (DHS) recorded 103 cases of Lyme disease in California in 2003 (CDHS 2003b). A 2002 study showed that the lengths of the periods with nymphal densities exceeding recorded yearly peaks in the woodlands were associated positively with rainfall and negatively with maximum air temperatures during April–May (Eisen, Eisen et al. 2002).

Nymphal densities in oak/madrone woodland typically started to decline when mean maximum daily air temperatures exceeded 23°C (74°F). Nymphal densities were higher in dry oak/madrone, relative to moist redwood/tanoak woodland from mid-March to late May 2000, similar in both habitat types in early June, but higher in redwood/tanoak woodland from late June onwards (Eisen, Eisen et al. 2002).

4.5.4 Hantavirus Pulmonary Syndrome (HPS)

In recent years, wetter conditions contributed to the outbreak of cases of Hantavirus in the Western region, particularly in the Four Corners area (National Assessment 2001). Hantavirus pulmonary syndrome (HPS) was first confirmed in California in 1993. Like Valley Fever, hantavirus is a risk factor influenced by climate conditions. Of the 19 cases of HPS identified in California in 1993, 10 died (CDHS 1999). It has been suggested that following the 1991–1992 El Niño, vegetation increased in the Four Corners region, causing a dramatic explosion of rodent populations, due to the greater availability of food resources (CDC 2000). Following the El Niño event, the deer mouse population was 10 to 15 times higher than average (Glass, Cheek et al. 2000), and the 1993 HPS outbreak could be traced to this increased abundance (Zeitz, Butler et al. 1995).

Precipitation, habitat structure, and food resources influenced population dynamics, viral transmission and hantavirus persistence, according to Abbott et al. (Abbott, Ksiazek et al. 1999). This study found that transmission of hantavirus was bimodal and associated with spring and autumn deer mouse reproductive activity, and that horizontal transmission may increase during the more active seasons. Mills et al. in 1999 found that prevalence of prevalence of hantavirus antibody showed seasonal and

Some Effects of Weather and Climate on Vector- and Rodent-borne Diseases[a]

Vectorborne pathogens spend part of their life cycle in cold-blooded arthropods that are subject to many environmental factors. Changes in weather and climate that can affect transmission of vectorborne diseases include temperature, rainfall, wind, extreme flooding or drought, and sea level rise. Rodent-borne pathogens can be affected indirectly by ecological determinants of food sources affecting rodent population size, and floods can displace and lead them to seek food and refuge.

Examples of temperature effects on selected vectors and vectorborne pathogens

Vectors

- Survival can decrease or increase depending on the species
- Some vectors have higher survival at higher latitudes and altitudes with higher temperatures
- Changes in the susceptibility of vectors to some pathogens (e.g., higher temperatures reduce the size of some vectors but reduce the activity of others)
- Changes in the rate of vector population growth
- Changes in feeding rate and host contact (which may alter the survival rate)
- Changes in the seasonality of populations

Vectorborne Pathogens

- Decreased extrinsic incubation period of pathogen in vector at higher temperatures
- Changes in the transmission season
- Changes in distribution
- Decreased viral replication

Examples of effects of changes in precipitation on selected vectorborne pathogens

Vectors

- Increased rain may increase larval habitat and vector population size by creating a new habitat.
- Excess rain or snowpack can eliminate habitat by flooding, thus decreasing the vector population size.
- Low rainfall can create habitat by causing rivers to dry into pools (dry season malaria).
- Decreased rain can increase container-breeding mosquitoes by forcing increased water storage.
- Epic rainfall events can synchronize vector host-seeking and virus transmission.
- Increased humidity increases vector survival; decreased humidity decreases vector survival.

Vectorborne Pathogens

- Few direct effects, but some data on humidity effects on malarial parasite development in the anopheline mosquito host.

Vertebrate Host

- Increased rain can increase vegetation, food availability, and population size.
- Increased rain can also cause flooding and decrease population size but increase contact with humans.
- Decreased rain can eliminate food and force rodents into housing areas, increasing human contact, but it can also decrease population size.

Increased Sea Level

- Alter estuary flow and change existing salt marshes and associated mosquito species, decreasing or eliminating selected mosquito breeding sites (e.g., reduced habitat for *Culiseta melanura*).

[a] The relationship between ambient weather conditions and vector ecology is complicated by the natural tendency for insect vectors to seek out the most suitable "microclimates" for their survival (e.g., resting under vegetation or pit latrines during dry or hot conditions or in culverts during cold conditions).

Source: Gubler, Reiter et al. 2001; National Assessment 2001 multiyear patterns (Mills, Yates et al. 1999). Their findings were consistent with horizontal transmission. They also showed that the incidence of HPS infection was higher in older mice.

4.5.5 Plague

Some studies have found that ambient temperature, rainfall, and relative humidity—along with vegetation—affected the seasonal abundance of rodent fleas in the western United States. Climatic events, such as periods of increased precipitation or drought, also strongly affect rodent population dynamics, largely through effects on food availability. Flea-borne plague incidence has been found to rise in conjunction with increasing rodent populations following unseasonable winter-spring precipitation in New Mexico. Responses of both fleas and rodents to climatic factors vary considerably from species to species. The association of climate and habitat on the incidence of human plague somewhat resembles that postulated for the effects of these factors on the occurrence of human hantavirus cases (Gubler, Reiter et al. 2001).

Asian tiger mosquito *(Aedes albopictus).* Since its accidental introduction into the United States in the 1980s, the Asian tiger mosquito has expanded its range and has found its way to California. Alto et al. researched how the mosquitoes performed at different temperatures. Data showed that populations at higher temperatures had extremely high rates of population increase.

The tiger mosquito can be a successful vector of such diseases as encephalitis, yellow fever, and dengue fever. It now appears that if current warming trends continue, the vector's range could be expanded. In areas where it has become firmly established, *Ae. albopictus* has displaced the most common mosquitoes found in those areas (Alto and Juliano 2001).

A small number of Asian tiger mosquitoes were discovered in Oakland during the late 1980s, but they did not survive. Another batch found in Houston managed to multiply and spread to the Atlantic Ocean and as far north as Iowa. Now, they inhabit 25 states (KOVR 13 2001).

4.5.6 Dengue Fever

About 50%–60% of the projected global population would be at risk for dengue transmission, compared with 35% of the world's today under 2 × CO_2 scenarios. Climate change is likely to increase the area of land with a climate suitable for dengue fever transmission, putting a large amount of the human population at risk (Hales, de Wet et al. 2002). For new areas not currently at risk that experience at least a doubling in calculated potential transmission, an additional 195 million people would be at risk for dengue due to climate change from a doubling of CO_2. (Patz, Martens et al. 1998).

CDC Arbovirus Surveillance and Response Activities

Surveillance

Arbovirus transmission within the United States is monitored by state and local health departments and the Centers for Disease Control and Prevention, Division of Vector-Borne Infectious Diseases (CDC-DVBID). The CDC obtains information through well-organized, systematic processes (e.g., National Electronic Telecommunications System Surveillance (NETSS)) and through a loosely organized network of workers in both state and local health departments and municipal mosquito and vector control agencies. Incoming information is received via phone, fax, mail, and an e-mail listserver (VECTOR) maintained by DVBID.

Human arbovirus cases are required to be reported by the state health departments and are monitored through NETSS, as are other reportable diseases in the country. Summaries of arbovirus cases are routinely disseminated to all 50 state health departments and certain key counties and diagnostic laboratories through the VECTOR listserver.

The arboviral equine encephalitides also cause veterinary disease, and cases may be reported to health or agriculture departments in the states. Certain health departments and veterinary diagnostic laboratories, including the U.S. Department of Agriculture-National Veterinary Services Laboratory, provide information regarding veterinary cases to CDC-DVBID. This information is summarized and disseminated via the VECTOR list server.

Nationwide, routine entomologic and environmental surveillance for arbovirus transmission activity is conducted by certain states that maintain intensive, statewide surveillance programs to monitor enzootic and epizootic arbovirus transmission activities. A few large counties and municipal mosquito control districts also conduct surveillance programs. CDC-DVBID supports these surveillance programs.

Response

Information is regularly evaluated on environmental surveillance and human and veterinary cases, and summaries are provided to health department workers via the VECTOR list server. If trends suggest increases in transmission activity or abnormally early or late transmission activity, CDC-DVBID alerts the state health department(s) involved and offers diagnostic laboratory support and on-site epidemiologic assistance by DVBID staff in evaluating the epidemic, enhancing surveillance activities, and coordinating emergency vector control activities.

Gaps in Surveillance and Response Capabilities

Gaps in surveillance and response capabilities are primarily related to the lack of surveillance infrastructure and lapse in communication systems. First, human case surveillance via NETSS is slow. The time lag between the diagnosis and confirmation of an arbovirus case and its appearance in NETSS is often quite long. Moreover, results of human diagnostic tests done in commercial laboratories may not be communicated to the state health department.

Veterinary case surveillance and reporting of cases needs to be better integrated with public health activities. Veterinarians sometimes do not obtain samples or request appropriate diagnostic testing. Results of samples that are tested often are not communicated to state or county health departments for timely evaluative follow-up, and few states require reporting of veterinary arbovirus cases. Better communication between human public health agencies, veterinary services, and organizations is essential.

Environmental and entomologic surveillance programs monitoring arbovirus transmission activity in vectors and vertebrate hosts are highly variable. Some states (e.g., California, Florida, New Jersey) maintain well-designed, comprehensive surveillance programs that monitor enzootic and epizootic transmission activity, veterinary cases, and human cases. Within several states, large counties (e.g., Harris County, Texas) also maintain intensive environmental surveillance programs. Other states and/or counties maintain only marginally effective or no environmental or veterinary surveillance programs. Support for arbovirus surveillance programs is frequently a very low priority in state health departments and interest and capability regarding arboviruses have lessened over the past 20–30 years. Finally, surveillance and reporting technique differences make data evaluation difficult.

In summary, there is no systematic method of assembling a national database of environmental or veterinary surveillance data, and most data are provided to CDC on a voluntary basis. Guidelines for arbovirus surveillance have been published, but the infrastructure required to implement effective surveillance and prevention programs is not available.

Sources: Gubler, Reiter et al. 2001; National Assessment 2001

Although such areas would include the temperate United States, housing structure and piped sanitation are also major determinants of disease risk.

4.5.7 Malaria

Since 1957, most malaria diagnosed in the United States has been imported. About 1,200 cases of malaria are reported annually, making it the most common imported vectorborne disease, and many cases likely go unreported. There are reports of malaria acquired through local mosquito transmission in nearly all parts of the United States, and this number may be increasing because of increased immigration/travel. Most cases occur in rural areas among migrant farm workers. Although such locally acquired malaria cases result in only a few cases per outbreak, many U.S. areas are at risk for limited local transmission (Gubler, Reiter et al. 2001). Warmer temperatures shorten the parasite's required development time inside its mosquito host.

Research Needs

1. Climate change is likely to affect the transmission patterns of vectorborne pathogens, but more research is needed to study transmission dynamics, including reservoir host and vector ecology. There is a need for information on how zoonoses persist in nature and what triggers their amplification and initiation of secondary cycles that increase the risk of human infection. Some diseases may increase, while others could decrease. How these pathogens persist and what triggers amplification must be understood before the role of weather and long-term climate trends can be fully determined.
2. Further research is needed on specific conditions that may result in outbreaks of infectious diseases such as cocci and West Nile virus. Looking into quantitative analysis of incidence data in conjunction with time-series climate data is an example.
3. To better examine the relationship that exists between climatic variability and HPS incidence, it may be necessary to analyze factors (e.g., temperature, precipitation, elevation, vegetation density) that may influence fluctuations in rodent populations. Weather monitoring stations, global positioning systems, vegetation surveys, as well as satellite-based remote sensors can be used as tools for data collection.
4. It is well established that climate is an important determinant of the spatial and temporal distribution of vectors and pathogens, and that biological systems such as birds and insect species are already responding to climate change. In theory, a change in climate would be expected to cause changes in the geographical range, seasonality (intra-annual variability), and in the incidence rate. The detection and then attribution of such changes to climate change is an emerging task for scientists. Priority research areas include improved surveillance systems and rapid diagnostic tests. New approaches to monitoring, such as frequent and long-term sampling to monitor the full range of specific vector species, are necessary in order to provide

convincing direct evidence of climate change effects. Improving rapid diagnostic tests for pathogens will facilitate treatment and help control the spread of vectorborne diseases.

5. There is a need to reassess the appropriate levels of evidence, including dealing with the uncertainties attached to detecting the health impacts of global change (Kovats, Campbell-Lendrum et al. 2001). Only limited databases are available to address the health impacts of extreme climate variability and change. Much of the information comes from epidemic investigations in which researchers focus their attention on a single event and gather data for only a short period of time.
6. A concerted effort to acquire more complete, long-term data sets is essential. Resolving the many questions about associations among weather, climate, and disease requires: (1) the identification of model systems or diseases that allows the development of long-term, high-quality data sets, and (2) sustained funding to make this research possible.
7. When long-term, high-quality data sets are available, they could be used to conduct system-modeling of transmission risk under future climate scenarios.
8. Research is needed to determine predictable climate patterns that may provide early warning systems (e.g., the El Niño Southern Oscillation, or ENSO).
9. Further research is needed to analyze habitat change under a changed climate and what the potential effects could be on disease vectors and intermediate hosts.
10. Systems need to be designed and implemented to facilitate the effective and rapid electronic exchange of surveillance data.

4.6 Infectious Waterborne Diseases

In the United States, more than 200 million people have direct access to disinfected public water supply systems, yet as many as 9 million cases of waterborne disease are estimated each year (Rose, Epstein et al. 2001). Data on drinking water outbreaks in the United States from 1948 to 1994 from all infectious agents demonstrated a distinct seasonality, a spatial clustering in key watersheds, and a statistical association with extreme precipitation (Curriero, Patz et al. 2001). Thus, this suggests that in certain watersheds, by virtue of the land use, fecal contaminants from both human sewage and animal wastes are transported into waterways and drinking water supplies by precipitation events.

Cryptosporidium parvum is a common cause of diarrhea in AIDS patients in both the developed and developing worlds, with reported prevalence rates of 3.6% in the United States to about 50% in Africa. One year after a large Milwaukee episode (with over 400,000 cases), a cluster of cryptosporidiosis cases and deaths among AIDS patients in Las Vegas (Clark County), Nevada, alerted health officials to another waterborne outbreak. The Nevada outbreak was associated with water from Lake Mead that was both filtered and chlorinated. Researchers in Brazil reported that *Cryptosporidium* was the most common cause of diarrhea in AIDS patients, and disease incidence showed a distinct seasonality, suggesting an association with rainfall (Rose, Epstein et al. 2001). In California, HIV-infected persons and other immunocompromised individuals (e.g., cancer patients) are at high risk for serious illness or fatality from cryptosporidiosis.

In Southern California, rising sea level will exacerbate saltwater intrusion into freshwater aquifers and impact the quality of surface water supplies (Beuhler 2003). In addition, if combined sewer overflow (CSO) events continue to discharge untreated wastewater during storm events, they may pose a greater health risk, should the frequency or intensity of storms increase (National Assessment 2001).

A strong association was detected between precipitation and water pollution that may be relevant to studies of potential health effects associated with climate change (Dwight, Semenza et al. 2002). Data showed that beaches next to rivers had the highest bacterial levels in both wet and dry seasons. Precipitation was significantly associated with water discharged from rivers; river discharge was significantly associated with bacterial levels. Swimming at beaches near rivers may pose a significant public health risk (Dwight, Semenza et al. 2002).

4.6.1 Diarrheal Diseases (Cholera)

Marine phytoplankton and zooplankton can shelter a dormant form of cholera that becomes infectious under the right conditions (e.g., temperature and nutrient levels) (USEPA 1997). The link between climate and cholera has become stronger in recent decades. The role ENSO plays in the variability of cholera has intensified—with cholera increasing after warm events and decreasing after cold events. The climate-cholera connection breaks down between events (Rodo, Pascual et al. 2002).

4.6.2 Fish Poisoning and Harmful Algal Blooms

Marine systems and climate are closely related. Direct weather associations have been documented for contamination of produce and seafood by waterborne pathogens. In fact, the World Health Organization is examining a link in Europe between rising ambient temperatures and an increase in food-borne diseases such as those caused by salmonella and campylobacteria (Rose, Epstein et al. 2001; WHO 2003).

Marine algal toxins impact human health through seafood consumption and respiratory routes. In addition to foodborne poisonings, toxins from two dinoflagellate sources are aerosolized to impact human health through the respiratory route (Van Dolah 2000).

Ciguatera is the most frequent cause of human illness caused by ingestion of marine toxins. Increases in ciguatera may result if the climate continues to warm. Ciguatera may be an indicator of environmental disturbance in tropical marine ecosystems. One study found strong positive correlations between the annual incidence of fish poisoning and local warming of the sea surface (Hales, de Wet et al. 2002).

Over the past three decades, the frequency and global distribution of toxic algal incidents appear to have increased, and human intoxication from algal sources has occurred. This increase is of particular concern since it parallels recent evidence of large-scale ecologic disturbances that coincide with trends in global warming. Events such as El Niño for example, have been linked with the occurrence of diseases in marine species (Van Dolah 2000).

Higher surface temperatures stimulate the growth of certain species of algae, in particular toxic "red tides." Food poisoning to humans occur when fish consume those algae (USEPA 1997). A study was conducted where embryos of Medaka fish were exposed to red tide toxins. Upon hatching, morphologic abnormalities were detected. Red tides neurotoxic effects have been documented. The observation of developmental abnormalities after red tide toxin exposure identifies a new spectrum of adverse events that could occur following exposure to *Gymnodinium breve* red tide events (Kimm-Brinson and Ramsdell 2001).

Blue-green algae toxicosis has been reported following analysis of samples collected from a pond where cattle had died in Colorado. A strong wind had concentrated algae on one side of the pond to which cattle had access. Two factors that lead to high concentrations of algae are good growing conditions (i.e., warm stagnant water with ample nutrients), and a breeze that blows across the water, allowing the organisms to concentrate near a shore (Puschner, Galey et al. 1998).

4.6.3 Vulnerable Populations

Children and any immunocompromised individuals (including those with HIV/AIDS), persons undergoing chemotherapy, or those taking steroids following transplant surgery are at risk from serious illness from ingesting waterborne pathogens.

4.6.4 Adaptation

Demand for better health protection and reporting warrants better outbreak management of water-related health impacts of global climate change (Kistemann, Herbst et al. 2001). Other strategies include surveillance systems, as well as improved water systems and engineering.

Drinking water quality is protected by federally established minimum standards passed under the federal Safe Drinking Water Act, first enacted in 1974. There are legally enforceable National Primary Drinking Water Regulations (NPDWRs or primary standards), or maximum contaminant levels (MCLs), for more than 80 contaminants; the list includes inorganic chemicals, organic chemicals, radionuclides, and microorganisms. States are responsible for enforcement, although the federal government maintains an oversight role. These rules apply to 55,000 community water systems that are public systems serving people year-round (Rose, Epstein et al. 2001).

Primary treatment of water to reduce microbial contamination involves the addition of a disinfectant such as chlorine. Despite federal regulations and treatment technologies, maximum contaminant level violations and violations of specific treatment standards are reported. In addition, some households, especially in rural areas, rely on untreated water such as water from shallow wells for part or all of their residential needs. Also, it is now known that certain emerging pathogens can pass through existing filtration and disinfection systems, among them *Cryptosporidium*. Water chlorination, a widely used method of disinfection, is not as efficient as ozone for inactivating the *Cryptosporidium* oocysts.

The Safe Drinking Water Act was substantially amended in 1996 to include new provisions for source and groundwater protection and improved enforcement and oversight of water suppliers. In 1998, the federal government began implementing a "Clean Water Action Plan," a primary focus of which is watershed protection. Implemented by the EPA, the U.S. Department of Agriculture, and state, tribal, and local governments, the Action Plan involves preparation of unified watershed assessments, development of strategies for watershed restoration and pollution prevention, and provision of small federal grants to local organizations interested in watershed protection (Rose, Epstein et al. 2001).

Currently, in most states, fecal coliform monitoring determines when beaches and shellfish beds are closed. Several states, realizing that fecal coliform is an ineffective measure of risk, implement *Enterococci* monitoring for marine waters; for freshwater beaches, *E. coli* monitoring is recommended. In some states such as California, a virus standard has even been discussed (Rose 2001).

One of the disadvantages of the current system is that waterborne disease outbreaks are detected after the fact, after the contamination event and after individuals have become ill. The disease surveillance system is incapable of detecting outbreaks when diagnosed cases are not reported to the health department, such as when mild symptoms are attributed to other causes or when health problems are not medically treated. In addition, delays exist in detecting outbreaks because of the time required for laboratory testing and reporting of findings.

Research Needs

1. Improved assessment of land use effects on water quality, through better assessment at the watershed level, of the transport and fate of microbial pollutants associated with rain and snowmelt.

2. Research is needed to identify high-risk watersheds that are prone to threaten water quality under conditions of extreme climate variability.

3. Studies are needed to determine the most effective ways to protect watersheds from agricultural contamination, such as runoff from livestock operations.

4. Climate change is projected to alter patterns of runoff in California. Research is needed to identify links between altered runoff (e.g., earlier snowmelt) and water quality, as well as availability.

5. Improved surveillance methods and systems are needed to prevent waterborne disease outbreaks, including better spatial and temporal resolution of reporting.

6. Epidemiologic studies that quantify the risks associated with multiple etiologic agents are needed.

7. Improved techniques for molecular tracing of waterborne pathogens would enhance the capacity to accurately identify the source of contamination.

8. Research is needed to better delineate the links between drinking water, recreational exposure, and food-borne disease monitoring.

9. Research is needed to analyze the relationships between precipitation, streamflow, and risk from contamination of beaches during recreational use—particularly under a changed climate.

10. There is evidence that the marine ecology is sensitive to changes in climate. Further research is needed to describe links between the marine ecology and toxic algae.

11. Vulnerability assessment and improved water and wastewater treatment systems.

12. Event monitoring, and development and implementation of better monitoring tools for waterborne microorganisms, are imperative. These activities need to be tied to watershed descriptors and hydrologic models for the development of water quality models for key pathogens.

13. Vulnerability assessments of communities and ecosystems with respect to the effects of impaired wastewater management could identify priority areas for upgrades.

14. Wastewater management also can be improved. Although most large urban centers have well-developed systems to transport, treat, and discharge wastewaters, these systems are aging and becoming overburdened by increasing population. Weather perturbations, such as increased precipitation, can increase the load to combined sewer systems and sanitary sewers through increased inflow and infiltration. To effectively treat wastewater under these conditions, facilities must increase their capacity and storage and improve their process control. Research is needed to optimize these systems under conditions of these increased loads.
15. Non-point sources such as septic tanks are a big concern for popular tourist areas and coastal communities. The change in management of wastes in these areas will be expensive and need to be fully examined. Assessment of the impacts of subsurface disposal on ground water and surface microbial water quality is needed for appropriate decisions to be made. Particularly, in light of the possible change in the rainy season and storms that could change the contamination of surface and ground waters (Rose, Epstein et al. 2001).
16. Watershed protection will continue to be an extremely important factor influencing water quality. Further research is needed to identify how watershed management can directly or indirectly affect source water and finished water quality, as well as recreational sites and coastal waters. Research is needed to identify better farming practices that will capture and treat agricultural wastes and enhance surrounding vegetation buffers— along with improved city disposal systems to capture and treat wastes. Such measures would help to reduce the runoff of nutrients, toxic chemicals, trace elements, and microorganisms flowing into reservoirs, ground water, lakes, rivers, estuaries, and coastal zones. For urban watersheds, more than 60% of the annual load of contaminant is transported during storm events. Research is needed to improve monitoring tied to hydrologic quantity and quality models, which will improve the assessment and the changes needed in watersheds to protect water quality for downstream users and ecosystems (Rose, Epstein et al. 2001).

4.7 Other Infectious Diseases

4.7.1 Coccidioidomycosis (Valley Fever)

Increased aridity and eventual desertification from increasing temperatures may increase the potential for infection. Cocci, for example, is spread by dust, often preceded by increased rain. A well-documented cocci outbreak followed the 1994 Northridge, California, earthquake, when 317 cases were seen in Ventura County and Simi Valley (Schneider et al. 1997). Global warming and population growth in arid areas such as the U.S. Southwest are likely to increase the risk of such hazards (Bernard, Samet et al. 2001).

Incidence of the disease varies seasonally and annually, due to changing climatic conditions (Kolivras and Comrie 2003). Temperature, precipitation, humidity, wind and the occurrence of dust storms have been shown to affect either the growth of *Coccidioides immitis* and/or distribution of arthrospores. Table 2 displays the association between cocci incidence and selected environmental/climatic variables in Maricopa County, Arizona.

Table 2. Association between cocci incidence and selected environmental and climatic variables

TABLE. Association* between coccidioidomycosis incidence and selected environmental and climatic variables — Maricopa County, Arizona, 1998–2001

Variable	RR†	(95% CI§)	p value
Building permits	1.0	(1.0 –1.0)	0.4315
Palmer Z Index¶	0.921	(0.874–0.970)	0.0018
PDSI**	0.939	(0.897–0.983)	0.0070
2 mos mean wind	0.965	(0.858–1.086)	0.5541
Wind velocity	0.835	(0.728–0.957)	0.0094
Temperature average over 3 mos	1.012	(1.003–1.020)	0.0087
Dust (PM10)††	1.015	(1.007–1.024)	0.0002
Rain	0.797	(0.681–0.933)	0.0048
Rain 3 mos before	0.926	(0.796–1.076)	0.3146
Rain 5 mos before	0.968	(0.836–1.121)	0.6672
Proportion 2 mos rain to 7 mos rain§§	0.554	(0.331–0.930)	0.0253
Cumulative rain, 2 mos	0.844	(0.760–0.937)	0.0015
Cumulative rain, 7 mos	0.860	(0.814–0.908)	<0.0001

* Determined by Poisson regression analysis.
† Relative risk.
§ Confidence interval.
¶ Short-term drought index.
** Palmer Drought Severity Index, a measure for long-term drought severity.
†† Concentration in the air of suspended particulate matter ≤10 microns.
§§ Cumulative rainfall during the preceding 2 months in proportion to cumulative rainfall during the preceding 7 months.

Source: CDC 2003 www.cdc.gov/mmwr/preview/mmwrhtml/mm5206a4.htm

The majority of human infections seem to occur during the windy dusty periods following the wet season (Kolivras, Johnson et al. 2001). In the early 1990s, California experienced an epidemic of Valley Fever that was linked to variability in precipitation. The epidemic followed five years of drought in California (Kolivras, Johnson et al. 2001). A Valley Fever outbreak in California in 1991—with south central Tulare County having the highest attack rate—was preceded by an unusually rainy spring. (Durry, Pappagianis et al. 1997).

A direct temporal relationship between dust storms and increased incidence of cocci was established by a study conducted by Williams et al. in 1979, where 18 new cases of cocci emerged two to four weeks after the storm (Williams, Sable et al. 1979).

A 1997 study by Schneider et al. examined an earthquake event with reference to cocci incidence, (Schneider et al. 1997) and data suggested that earthquakes may be implicated in cocci outbreaks. Disease onset for acute cocci cases peaked two weeks after the earthquake, and data analysis revealed that being in a dust cloud and time spent in a dust cloud significantly increase the risk of being diagnosed with acute cocci. The airborne dust associated with landslides triggered by the earthquake was implicated in the higher incidence. Dust storms are frequently followed by outbreaks of cocci. Weather and susceptible people in endemic areas could be factors that account for a marked increase in cocci incidence. Figure 4 shows the geographic distribution of coccidioidomycosis and areas of the United States and northern Mexico that are considered endemic for Valley Fever (Kirkland and Fierer 1996).

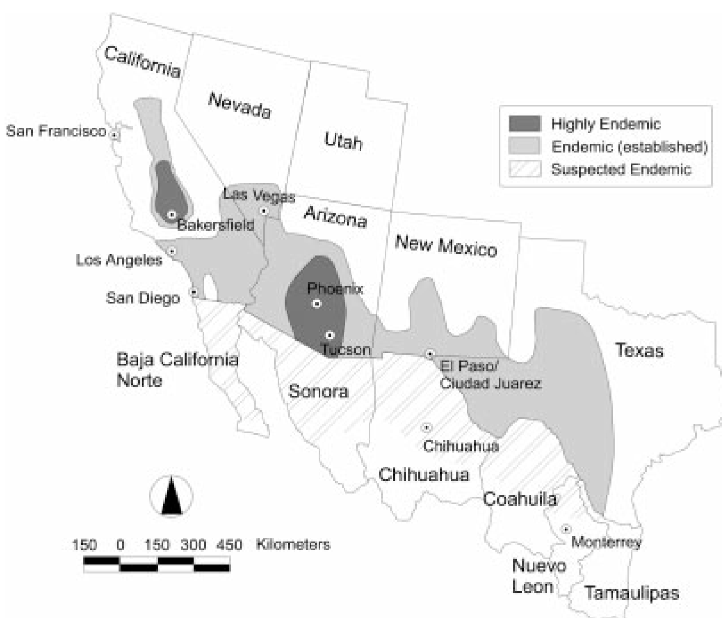

Figure 4. Areas of the United States and northern Mexico that are considered endemic for Valley Fever

Source: Kirkland and Fierer 1996.

The 1992 cocci outbreak in California (4,516 cases in 1992, up from 1,200 cases in 1991) was associated with weather conditions (i.e., drought followed by heavy rains), as well as a larger susceptible population (Pappagianis 1994). Similarly, climatic factors may have played an important role in the increase in cocci incidence in Arizona (a growing health problem there, as evidenced by 255 cases in 1990 and 623 in 1995) (CDC 1996;

Ampel, Mosley et al. 1998). The recent Arizona cocci epidemic is attributed to seasonal peaks of incidence that may be related to climate, where a high correlation between incidence of disease and rain, temperature, and dust months prior to the outbreak was identified. Peak periods of cocci incidence were found to occur during the winter (CDC 2003).

Older travelers to a cocci-endemic area and being exposed to dust through excavation activities caused 27 of the 35 travelers to have flu-like symptoms, of which 27% met the definition for coccidioidomycosis. Cocci outbreaks occur when susceptible people are exposed to dust carrying airborne *arthroconidia* from natural disasters, storms, and earth excavations (CDC 2000b).

In a study in Greece, factors thought to contribute to the extraordinary increases in cocci cases were a drought of five to six years' duration; abundant rain in 1991 and 1992; construction of new buildings; and arrival of new, susceptible individuals to the endemic areas. Figure 5 illustrates the seasonal relationship between amount of rainfall and number of cocci cases through the 1991 outbreak in Kern County, California. (Pappagianis 1994).

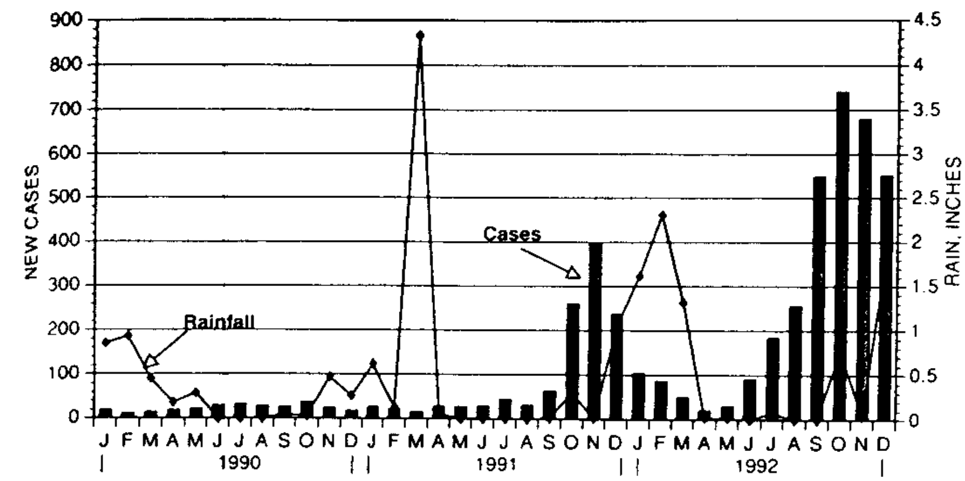

Figure 5. The seasonal relationship between amount of rainfall and number of cases of cocci in humans in Kern County, California, 1990–1992
Source: Pappagianis 1994.

Models were developed to describe relationships between valley fever incidence and climate conditions and variability; it was determined that months with high incidence can be predicted more accurately than months with low incidence (Kolivras and Comrie 2003).

Pulmonary cocci, which was seen after the 1994 Northridge earthquake, is an example of an infectious disease following a disaster, due to increased dust levels. In Southern California, cocci increases every time construction work begins and dirt is disrupted and turns into dust (Zibulewsky 2001).

A windy month immediately following a wetter than normal season is more likely to result in increased cocci incidence in Kern County, California. Monthly precipitation, wind speed, and temperature anomalies are the strongest predictive variables, explaining up to 20% of incidence anomalies. Unusually wet periods 9 to 10 months prior, followed by unusually dry, warm, and windy periods 4 to 6 months prior, are significantly associated with the Kern county cocci outbreak (Zender and Talamantes 2003).

Jinadu (1995) reported that a Valley Fever epidemic in California in the 1990s that was linked to variability in precipitation was preceded by five years of drought. Another study by Hugenholtz (Hugenholtz 1957) did not find strong correlations between rainfall and cocci incidence, but found stronger relationships with temperature and dust storms.

4.7.2 Kawasaki Disease

Kawasaki Disease (KD) is a common childhood vasculitis of unknown etiology. The skewed ethnic distribution and seasonality are consistent with the hypothesis that KD is an infectious disease that is influenced by environmental and genetic factors. The overall annual incidence of KD in children < 5 years of age ranged from 8.0 to 15.4/100,000. The incidence of KD was inversely associated with average monthly temperature and positively associated with average monthly precipitation (Bronstein, Dille et al. 2000).

In 1997 and 1998, compared with the previous two years, the incidence for children < 5 years old increased by 30%. The number of cases peaked in March and had its nadir in September (Chang 2002). An infectious agent related to environmental and climatic cycles is suspected (CAP 2002).

4.7.3 Vulnerable Populations

Many studies found that blacks, Asians, Mexicans, Filipinos, and Native Americans are more likely to experience a severe form of valley fever than whites (Kolivras et al. 2003) Persons of Filipino and African descent, immunocompromised individuals and pregnant women are at increased risk for disseminated cocci infection (Williams, Sable et al. 1979; Kirkland and Fierer 1996; CDC 2001b). Another study that looked at a cocci outbreak in California in 1991 found that being male (relative risk 2.5), black, or Asian (relative risk 4.8) was significantly associated with having the highest cocci attack rate (Durry, Pappagianis et al. 1997).

In 2001, the CDC determined that infants, pregnant women, persons of Filipino and African descent, and immunosuppressed persons are at increased risk for disseminated cocci infection (CDC 2001b). Also, a study conducted in 2000 found that cases of cocci are more likely to disseminate in people under the age of 5 and over the age of 50 (Kolivras et al. 2001). Cocci disproportionately affected persons > 65 years and those infected with human immunodeficiency virus (HIV) (CDC 1996; Ampel, Mosley et al. 1998).

Recent migration to a cocci-endemic area (Arizona) and various underlying medical conditions were associated with increased risk of developing acute cocci among elderly people (Leake, Mosley et al. 2000). In the study, elderly people with cocci had spent significantly less time in Arizona than controls and were more likely to have congestive heart failure or cancer, to have smoked, or to have taken steroids. Those on diuretics for hypertension or congestive heart failure are at higher risk of dehydration during heat waves.

Compared with 1995 and 1996, the KD incidence for children < 5 years old increased by 30% in 1997 and 1998. Asians had the highest incidence, with 35.3 cases per 100,000 children < 5 years old, followed by blacks (24.6) and whites (14.7) (Chang 2002). Asian/Pacific Islanders were at an increased risk for KD relative to all other ethnic groups combined (Bronstein, Dille et al. 2000).

4.7.4 Adaptation

Although dust reduction measures can help reduce exposure during times of increased coccidioidomycosis incidence, definitive control awaits the development of a safe, effective vaccine (Durry, Pappagianis et al. 1997). It is possible that wetter conditions would increase the potential of an outbreak and other climate-sensitive diseases such as plague, coccidioidomycosis, and Kawasaki disease. However, due to the capability of the public health system, it is unlikely that there will be large outbreaks of infectious diseases in the West. It is more likely that if climate gets warmer and wetter, the potential for small outbreaks from people carrying the diseases from other countries into the region would increase.

Research Needs

- Geographical analysis of cocci incidence in California can be compared to another endemic region to assess different incidence patterns across varied geology, topography, and land use. A predictive model of *C. immitis* response to climate can be developed through analysis of climate and cocci data (Kolivras and Comrie 2003).

4.8 Other Climate-related Health Issues

4.8.1 Agriculture

Water is vital for California, and most of the water is transported through a network of aqueducts, canals, and reservoirs—the largest in the world. The Colorado River and the Sierra Nevada mountain range are the two major sources of water for the arid regions. Climate change will affect the quantity of water received, as well as its timing, form, and location. Agriculture that uses irrigation will be affected, because more than 80% of the state's cropland is irrigated. California's farms depend heavily on managed water, and some consequences of climate change (such as droughts and floods) could have huge economic impacts (NOAA 2000).

4.8.2 Pesticides: Increased Exposure with Climate Change?

California has almost 28 million acres in agricultural production (CFBF 2000). Currently, about 200 million pounds of active ingredient pesticides are used in California each year (CA EPA 2002). According to the National Agriculture Assessment Group, climate change is expected to bring an increase in pest problems for most locations and most crops studied (NAAG 2002, 94). If an increase in pesticides is used to counteract the increase in pest problems, Californians could be more significantly affected than other areas of the country, because of the large amount of land in agricultural production in California.

A variety of pesticides have been linked directly to human disease, and many can harm ecosystems, which can have indirect but significant effects on humans. The specific risks for disease in humans depend on the pesticide used and the exposure. Agricultural pesticide use poses risks for farmers and farm workers, but also for the California population at large. In addition to those exposed occupationally, pesticide aerosols can drift to nearby communities and agricultural runoff can find its way into groundwater. Troiano et al. (2001) found residues for 16 active pesticide ingredients and breakdown products in California groundwater as a result of legal agricultural use. Some examples of suspected disease risks for pesticides commonly used in California are presented below.

Swan et al. found a significant decrease in sperm concentration and motility from men in Columbia, Missouri, when compared to samples from men in New York City, Minneapolis, or Los Angeles. The authors speculate that a plausible explanation for this discrepancy—which persisted after controlling for multiple confounding factors such as age, race, and smoking history—is that the Columbia men live in an agricultural area and are therefore exposed to greater concentrations of agricultural pesticides. They suggested further research to identify the cause (Swan, Brazil et al. 2003).

Lee and colleagues, 2002, using ambient air data provided by the California Air Resources Board and the California Department of Pesticide Regulation assessed inhalation risks to California communities from airborne agricultural pesticides. They found that "exposure estimates greater than or equal to non-cancer reference values occurred for 50% of the population (adults and children)" for several commonly used pesticides. They note that non-cancer risks, such as neurologic and respiratory effects, are greater for children (Lee, McLaughlin et al. 2002).

One indication of how disruptive pesticides can be for ecosystems comes from Sparling et al. (2001) who note that certain amphibian populations have been drastically reduced in the western United States over the past 10 to 15 years. The most severe declines in California have occurred in the Sierra Mountains, downwind of the intensely agricultural San Joaquin Valley. The authors believe their research provides evidence that "pesticides are instrumental in declines of these species" (Sparling, Fellers et al. 2001). Amphibians are "sentinel species" and their decline is often an indication that the viability of an ecosystem is declining. The pesticides diazinon and chlorpyrifos were found in a central California coastal watershed in sufficient quantities to be toxic to aquatic invertebrates. Migratory waterfowl, including endangered species and threatened salmonids, use this river system and could ingest toxic levels of these pesticides (Hunt, Anderson et al. 2003).

4.8.3 Marine Fisheries

Climate change will have important implications for marine ecosystems that support ecologically and economically important fish populations. As a result of changes in ocean conditions, the distribution and abundance of major fish stocks will probably change substantially. Figure 6 displays the changes in Southern California's marine ecosystem since the mid-1970s.

Increased warming of the waters off Los Angeles have resulted in a 50% decline of cold-water, northern fish species (like the greenspotted rockfish), while warm-water southern fish species (like the Garibaldi) have increased by 50%. In addition, decreased summer stream flow would increase the salinity of San Francisco Bay and the San Joaquin Delta, and changes in ocean currents would bring changes to marine communities (NOAA 2000).

The San Francisco Bay and Delta estuary comprise one of the United States' most significant and highly studied estuarine systems and have been described as "the most heavily invaded estuary in the world," with nearly 200 non-native species documented

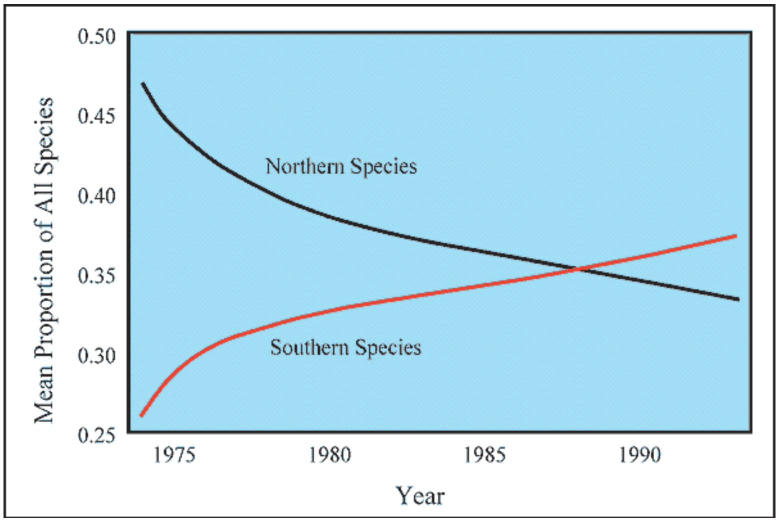

Figure 6. Changes in Southern California's marine ecosystem since the mid-1970s
(Redrawn with permission from: *Confronting Climate Change in California*. Union of Concerned Scientists 1999. The complete report can be accessed at www.ucsusa.org).

(USGCRP 1998). In some parts of the estuary, non-native species account for as many as 90% of the species and 97% of the total biomass.

The potential for rapid sea level rise has tremendous implications for the estuary and the humans who depend on it. The volume and timing of freshwater inflow to the estuary (which could change salinity distributions in the Bay/Delta) is also likely to be strongly affected by climate change.

Along the Pacific Coast, impacts to fisheries related to El Niño illustrate how climate directly affects fisheries on short time scales. Elevated sea surface temperatures associated with the 1997–1998 El Niño had a tremendous impact on the distribution and abundance of market squid, California's largest fishery by volume, and were implicated in high sea lion pup deaths in California waters.

4.8.4 Killer Bees (or Africanized Honey Bees, AHBs)

In 1956, Africanized honey bees were introduced into Brazil to breed bees better adapted to the tropics. Unfortunately, some of the bees escaped quarantine and bred with the Brazilian honey bees, and their progeny have since spread at a rate of 100 to 300 miles per year. To date, 12 California counties have reported AHB finds. Many scientists believe that AHBs will continue to spread and successfully over-winter in the United States' southern tier states. Figure 7 shows AHB distribution in 2003.

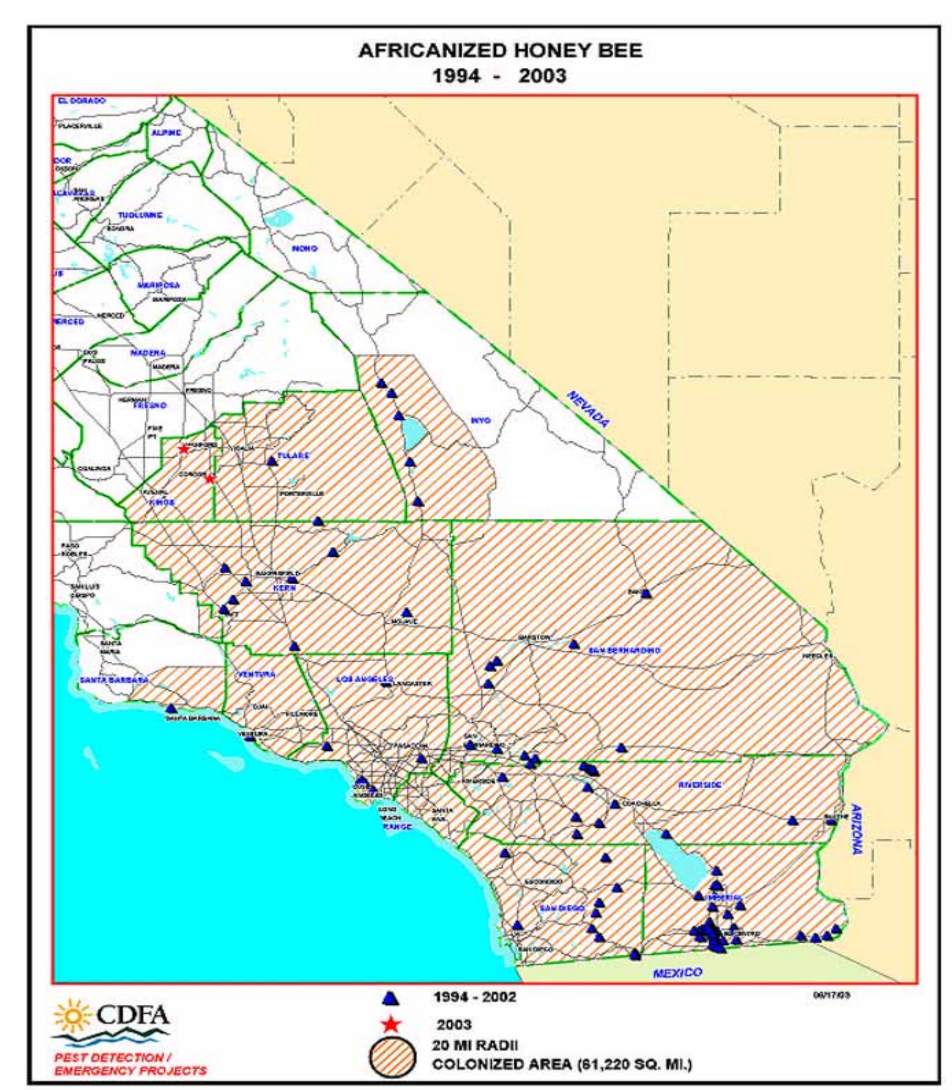

Figure 7. AHB distribution in 2003
Source: http://bees.ucr.edu/ahb-update.html AHB update. UC Riverside.

Africanized honey bees are partially limited by cold. In the tropics, AHBs are found in elevations up to 8,900 feet; thus summer invasions of mountains adjacent to Africanized areas in the United States may be expected. Competition with temperate-adapted bees, as well as climate factors, are limiting the spread of AHBs. Unless limited by natural disasters (e.g., fire) or density-dependent environmental factors (e.g., food, water, certain communicable diseases), the AHBs' population density will increase through swarming.

Africanized honey bees will nest in hollow trees and in debris among other trees; in arid regions, honey bee colonies are more commonly found near water sources. In theory, if climate change leads to wet winters and springs in Southern California, wildflower blooms could alter the distribution of AHBs.

Killer bees first made their way to California in Blythe in 1994. Los Angeles' first colony was discovered in the city of Lawndale as early as 1998. Today, most counties in Southern California are considered colonized by AHBs. Africanized honey bees swarm more, have shorter development time, and are more aggressive than European honey bees (University of Delaware 2002).

The dry cities have the most difficulty with the bees, because people are inadvertently giving them nesting sites. It is noteworthy to mention that firefighters could face a new hazard—that of AHBs.

4.8.5 Snake Bites

Snake bites may follow extreme events such as hurricanes, which could be caused by El Niño-type events. Presumably, snakes would be responding to a change in their habitat caused by changes in rainfall or disturbed nests. Increases in extreme storms could potentially alter human exposure to poisonous snakes.

Rattlesnakes are the only type of venomous snake found in Southern California. Another venomous snake found in California is the west coral snake, which prefers rocky areas, plains to lower mountain slopes; rocky upland desert in arroyos and river bottoms. Found from sea level to 5,900', its habitat ranges from central Arizona to southwest New Mexico south to Mexico (Leco 2003).

4.8.6 Vulnerable Populations

Several studies have reported an elevated risk of prostate cancer in farmers and farm workers. Mills and Yang (2002) looked at the relationship between Hispanic farm workers and specific chemicals. They "concluded that Hispanic farm workers with relatively high levels of exposure to organochlorine pesticides (lindane and heptachlor, organophosphate pesticides (dichlorvos), fumigants (methyl bromide), or triazine herbicides (simazine) experienced elevated risk of prostate cancer compared to workers with lower levels of exposure" (Mills and Yang 2003). Other diseases associated with pesticide exposure include pancreatic cancer (Clary and Ritz 2003); leukemia and stomach, cervix, and uterine cancers (Mills and Kwong 2001); brain and testicular cancer (Mills 1998); and fetal death due to congenital anomalies (Bell, Hertz-Picciotto et al. 2001).

Children are especially vulnerable to the harmful effects of pesticides because of their behavior, physiology, and developing neurological systems. They can be exposed to pesticides through air, water, dust, and soil contamination, and through contamination of farm worker parents' vehicles, clothing, and boots that are brought home. Lu and colleagues (1999) attempted to characterize children's exposure to organophosphate pesticides in an agricultural community. They checked urine samples, hand wipe samples, and house dust samples from children whose parents were farm workers or lived close to pesticide-treated orchards and compared them with controls. They found that the agricultural children had median pesticide metabolite concentrations that were five times higher than controls. They also found azinphos-methyl (a pesticide registered for agricultural use only) in every study home, providing "clear evidence that such pesticides move beyond the targeted application area" (Lu, Fenske et al. 2000, 301). Fenske and colleagues estimated exposure doses for children whose parents worked in agriculture. They found that more than half of the doses exceeded the EPA's chronic dietary reference dose during the spraying season for azinphos-methyl (Fenske, Kissel et al. 2000).

4.8.7 Adaptation

Integrated water resources planning is emerging as a tool to develop water supplies and demand management strategies that are less vulnerable to the impacts of global warming. These tools include water conservation, conjunctive use of surface and groundwater, and desalination of brackish water and possibly seawater (Beuhler 2003).

Research Needs

1. The response of plant pathogens and pests to climate change is highly uncertain, and therefore, changing demands for pesticides are also uncertain.
2. Effectiveness of Integrated Pest Management (IPM)—a strategy that uses a combination of techniques for long-term prevention and suppression of pests—needs further evaluation.
3. More research is needed to understand the effect of sea surface temperatures on toxic algae and the production of fisheries.
4. Ecological studies are needed on hazardous insects and reptiles (e.g., bees and snakes) with respect to climate variability.

Recommendations of the U.S. National Assessment, Health Report

In addition to the specific recommendations for research priorities in California listed at the end of each health outcome section above, these are the more generalized research recommendations that emerged from the U.S. Assessment on Climate Change, Health Panel Report (National Assessment 2001). Most of these nationwide recommendations also apply to California.

For Heat:

- improve the early prediction of these events by determining which weather parameters are important in the relationship between weather and health;
- improve urban design to limit the urban heat island effect by incorporating trees, shade, wind, and other heat-reducing conditions;
- conduct heat mortality modeling studies with future climate scenarios;
- conduct heat morbidity studies to better assess full health impacts of heat waves;
- improve understanding of weather's contribution to winter mortality (e.g., why influenza peaks in the winter).

For Extreme Precipitation:

- improve warning communication strategies to provide early, easily understood messages to the populations most likely to be affected;
- conduct research on the effectiveness of educational materials and early warning systems;
- conduct post-disaster disease surveillance;
- perform studies on long-term health effects from severe events, such as nutritional deficiency and mental health effects;
- standardize information collection after disasters to better measure morbidity and mortality;
- evaluate current urban and rural development practices on risk and, specifically, the effects of altered land use on vulnerability to extreme weather.

For Air Pollution:

- determine the association between weather and pollutants;
- identify health impacts of chronic exposure to high levels of ozone;
- identify health effects of ozone exposure in people with asthma and other lung diseases;
- characterize the interaction of ozone with other air pollutants;
- characterize the interaction of ozone and direct heat effects on mortality;
- identify the mechanisms responsible for the adverse health effects of ozone and other air pollutants in the general population and within susceptible subgroups;
- identify the measures that can modulate the impact of air pollution on health, such as nutrition and other lifestyle characteristics;
- perform urban weather modeling for inversions and other pollution-relevant wind or air mass patterns.

For Vectorborne Diseases:

- improve rapid diagnostic tests for pathogens;
- develop vaccines dengue fever, malaria, encephalitis, and other diseases;
- improve active laboratory-based disease surveillance and prevention systems at the state and local level;
- system-model transmission risk under future climate scenarios;
- study transmission dynamics (including reservoir host and vector ecology);
- improve surveillance systems for the arthropod vector and vertebrate hosts involved in the pathogen maintenance/transmission cycles, to allow for more accurate predictive capability for epidemic/epizootic transmission;
- develop more effective and rapid electronic exchange of surveillance data.

For Waterborne Diseases:

- identify links between land use and water quality, through better assessment at the watershed level of the transport and fate of microbial pollutants associated with rain and snowmelt;
- develop methods to improve surveillance and prevention of waterborne disease outbreaks, including better spatial and temporal resolution of reporting;
- conduct epidemiologic studies that quantify the risks associated with multiple etiologic agents;
- perform molecular tracing of waterborne pathogens for accurate source identification;
- identify links between drinking water, recreational exposure, and food-borne disease monitoring;
- identify links between marine ecology and toxic algae;
- conduct vulnerability assessment and improved water and waste water treatment systems.

General Conclusions of the U.S. National Assessment, Health Sector Report

The following general conclusions emerge from reviewing the impacts and adaptations in these major health outcome categories:

- Health impacts from climate variability and change may vary by location, population age group, and specific community health, sanitation, and existing or planned emergency response infrastructure. Effects depend on other environmental (e.g., land use) and socioeconomic conditions, and impacts across sectors are interrelated.
- Adapting to climate change threats (such as increased storm runoff, or possible air pollution) will likely have near-term benefits that apply to current deficiencies in infrastructure, although these have not been quantified.
- Adverse side effects from adaptation to climate change must be part of future assessments, due to the interrelatedness of impacts. Preventive measures for each outcome must consider broader ramifications (e.g., use of pesticides in agriculture or for vector control, or increased electricity demands from air conditioning).

Scientists and granting agencies should appreciate the diversity of potential health outcomes and exposure pathways associated with climate variability and change. Clearly there is an overarching need for interdisciplinary research and integration of databases across physical, biological, and sociological sciences.

5. Goals

The goal of the PIER-EA health-related climate change research is to help California anticipate potential health-related problems attributable to climate change and help enable researchers and decision makers to prepare for those impacts.

The achievement of that goal depends on the development of methods, tools, and analysis that addresses and mitigates the causes and impacts of heat waves, wildfires, extreme events, air quality, infectious vectorborne and waterborne diseases, other infectious diseases, and other climate-related health issues.

The PIER-EA program recognizes that much work is currently under way in these areas and seeks to draw from, build upon, and broaden the focus of those efforts. Whenever possible, PIER-EA will identify existing efforts and form partnerships to leverage resources.

5.1 Objectives

5.1.1 Heat Waves

A. **Evaluate the effect of heat waves on human health, as well as the current methods and tools for addressing those impacts.**

Activities needed: (1) Evaluate the effectiveness of early warning systems for heat waves. (2) Determine which weather factors are important to health. (3) Research the association between heat and morbidity and mortality. (4) Evaluate the feasibility and effectiveness of specialized health education efforts aimed at reaching susceptible populations. (5) Standardize methods of recording heat-related health outcomes. (6) Evaluate the importance of urban design to heat retention. (7) Assess the net annual health impacts, comparing both summer and winter mortality projections under climate change scenarios. (8) Determine whether a threshold temperature exists, above which Californians may suffer adversely.

5.1.2 Wildfires

A. **Assess climate change's contribution to wildfire risk and the impact of wildfires on human health.**

Activities needed: (1) Assess wildfire risks under a changed climate (particularly the effect of climate change on Santa Ana winds, winter precipitation, and peak summer temperatures). (2) Study the effect of climate change on plant pest infestation. (3) Evaluate the contribution of wildfires to health effects from compromised air quality. (4) Determine the effect of woodland fires on morbidity.

5.1.3 Extreme Events

A. **Study the contributions of extreme climatological events on human health in California, and improve methods for modeling and predicting public health impacts.**

Activities needed: (1) Improve downscaling of global climate models (GCMs). (2) Conduct post-disaster disease surveillance and studies on the long-term physical and psychological health effects from disasters. (3) Analyze non–climate risk factors—such as geographical topography, stream flow velocities, and coastal/floodplain development—that modify the impact of storms. (4) Determine the value of current urban and rural development practices on risk (specifically, the effects of altered land use on vulnerability to extreme weather). (5) Conduct flow studies to delineate toxic releases into water supplies and their potential health effects. (6) Conduct epidemiologic studies of the public health effects of flooding.

5.1.4 Air Quality

A. **Study the effects of climate change on air quality.**

Activities needed: (1) Evaluate the relationships between the emissions of air pollutants, climate change, and resulting air pollution. (2) Conduct basic atmospheric science on the association between weather and air pollutants (including boundary layer dynamics; urban heat island effects; and the contribution of transboundary pollution, dust, and/or precursors). (3) Improve air pollution models and their linkage with climate change scenarios. (4) Study the balance between heavy precipitation (as a tropospheric "cleansing" mechanism) versus heat-related or stagnant air mass exacerbation of pollution. (5) Develop better emission scenarios (including anthropogenic and vegetative emissions) to determine how changing energy demands will effect emissions. (6) Study the hypothesis of a link between stratospheric ozone and climate change, to determine whether ozone hole recovery could slow under a changing climate. (7) Evaluate the combined effects of temperature and humidity on air pollution. (8) Study the effect of weather on vegetative emissions and allergens (such as pollen) to determine if more pollen will be produced, if there will be a longer allergy season, and if a longer allergy season, run into summer high ozone pollution periods, could have synergistic adverse effects.

B. **Study the impacts of climate change-related shifts in air quality on human health.**

Activities needed: (1) Conduct studies to better understand exposure patterns and health effects from air pollutants. (2) Assess health risks that result from the use of technological adaptations that can increase air pollution (i.e., air conditioner use). (3) Assess the effects on human health of any new pesticides used as an insect control measure. (4) Further study the effects of climate on fine particulates on cardiovascular and lung disease. (5) Determine the relationship between ozone and direct heat effects on mortality.

5.1.5 Infectious Vectorborne Diseases

A. **Better define the relationships among climate change and vector ecology, and how those relationships affect the transmission of infectious vectorborne diseases.**

Activities needed: (1) Study transmission dynamics, including reservoir host and vector ecology, to better understand how these pathogens persist and what triggers amplification. (2) Determine specific conditions that may result in outbreaks of infectious diseases such as cocci and West Nile virus. (3) Analyze factors that may influence fluctuations in rodent populations, to better examine the relationship that exists between climatic variability and HPS incidence. (4) Reassess the appropriate levels of evidence, including dealing with the uncertainties attached to detecting the health impacts of global change. (5) Determine predictable climate patterns that may provide early warning systems. (6) Analyze habitat change under a changed climate and determine what the potential effects could be on disease vectors and intermediate hosts.

B. **Improve monitoring, diagnostic, and evaluation tools.**

Activities needed: (1) Improve surveillance systems, rapid diagnostic tests, and studies of the dynamics of the transmission of climate-related diseases to detect and attribute such changes to climate change.

C. **Improve data and modeling that addresses infectious vectorborne diseases.**

Activities needed: (1) Develop more complete, long-term data sets. Resolve questions about associations among weather, climate, and disease by identifying model systems or diseases that allow the development of long-term, high-quality data sets. (2) Employ the long-term, high-quality data sets developed under the previous activity to conduct system-modeling of transmission risk under future climate scenarios. (3) Design and implement systems to facilitate the effective and rapid electronic exchange of surveillance data.

5.1.6 Infectious Waterborne Diseases

A. **Evaluate the cause-and-effect relationships and risks of various climate change-related factors on infectious waterborne diseases.**

Activities needed: (1) Improve assessment of land use effects on water quality through better assessment (at the watershed level) of the transport and fate of microbial pollutants associated with rain and snowmelt. (2) Identify links between altered runoff (e.g., earlier snowmelt) and water quality, as well as availability. (3) Conduct epidemiologic studies that quantify the risks associated with multiple etiologic agents. (4) Better delineate the links between drinking water, recreational exposure, and food-borne disease monitoring. (5) Analyze the relationships between precipitation, streamflow, and risk from contamination of beaches during recreational use—particularly under a changed climate. (6) Identify and evaluate links between sea surface temperature, marine ecology, and toxic algae. (7) Assess the vulnerability of communities and ecosystems with respect to the effects of impaired wastewater management. (8) Assess the impacts of subsurface disposal on ground water and surface microbial water quality.

B. **Identify high-risk watersheds in California.**

Activities needed: (1) Identify high-risk watersheds in California that are prone to threaten water quality under conditions of extreme climate variability.

C. **Evaluate and improve tools and methods for addressing infectious waterborne diseases.**

Activities needed: (1) Determine the most effective ways to protect watersheds from agricultural contamination. (2) Improve surveillance methods and systems, including better spatial and temporal resolution of reporting. (3) Improve techniques for molecular tracing of waterborne pathogens. (4) Develop better monitoring tools and implement them for waterborne microorganisms.

5.1.7 Other Infectious Diseases

A. **Conduct studies and develop tools to evaluate the potential spread of cocci in California as a result of climate change.**

Activities needed: (1) Compare a geographical analysis of cocci incidence in California to another endemic region to assess different incidence patterns across varied geology, topography, and land use. (2) Develop a predictive model of *C. immitis* response to climate through analysis of climate and cocci data.

5.1.8 Other Climate-related Health Issues

A. **Evaluate the effect of climate change on pests, pesticides, and their ecological effects.**

Activities needed: (1) Estimate the changing demands for pesticides as plant pathogens and pests respond to climate. (2) Further analyze the effectiveness of Integrated Pest Management (IPM). (3) Conduct ecological studies on hazardous insects and reptiles in response to climate variability.

Table 3. Proposed research areas

Objective	
5.1.1.A	Evaluate the effect of heat waves on human health, as well as the current methods and tools for addressing those impacts.
5.1.2.A	Assess climate change's contribution to wildfire risk and the impact of wildfires on human health.
5.1.3.A	Study the contributions of extreme climatological events on human health in California, and improve methods for modeling and predicting public health impacts.
5.1.4.A	Study the effects of climate change on air quality.
5.1.4.B	Study the impacts of climate change-related shifts in air quality on human health.
5.1.5.A	Better define the relationships among climate change and vector ecology, and how those relationships affect the transmission of infectious vectorborne diseases.
5.1.5.B	Improve monitoring, diagnostic, and evaluation tools.
5.1.5.C	Improve data and modeling that addresses infectious vectorborne diseases.
5.1.6.A	Evaluate the cause and effect relationships and risks of various climate change-related factors on infectious waterborne diseases.
5.1.6.B	Identify high-risk watersheds in California.
5.1.6.C	Evaluate and improve tools and methods for addressing infectious waterborne diseases.
5.1.7.A	Conduct studies and develop tools to evaluate the potential spread of cocci in California as a result of climate change.
5.1.8.A	Evaluate the effect of climate change on pests, pesticides, and their ecological effects.

6. Leveraging R&D Investments

6.1 Methods of Leveraging

Much of the work identified in this roadmap would be collaborative with other entities; PIER-EA would either co-fund projects by other entities, or use outside funds to support PIER-EA efforts.

6.2 Opportunities

Co-sponsorship opportunities are likely with both the U.S. Environmental Protection Agency and the California Air Resources Board. Each of these organizations is interested in addressing health-related climate change issues. At this time, specific collaborative opportunities have not been identified.

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Appendix A
Current Status of Programs

This section outlines those efforts that most closely address health-related climate change issues and their impact on California.

Ongoing activities

Heat Waves and Wildfires

- **National Center for Atmospheric Research (NCAR), Environmental and Society Impacts Group.** This group maintains the Heat Wave Awareness Project website, which offers links to a network of information and ongoing research from national labs, government branches, universities, and community groups at www.esig.ucar.edu/heat/web.html.

- **U.S. Geological Survey's (USGS) Western Ecological Research Center, California State University, and others.** In "Reexamining Fire Suppression Impacts on Brushland Fire Regimes," USGS scientist Jon Keeley of the Western Ecological Research Center in Sacramento and his colleagues C. J. Fotheringham of California State University, Los Angeles, and Marco Morais (formerly of the Santa Monica Mountains National Recreation Area) reinforced an earlier view that the problem of wildfire destruction started with population growth into the foothills and associated fire suppression impacts on brushland fire regimes: California shrubland wildfires are increasingly destructive, and the problem is made worse by fire suppression, leading to larger, more intense wildfires. However, analysis of the California Statewide Fire History Database shows that, since 1910, fire frequency and area burned have not declined, fire size has not increased, fire rotation intervals have declined, and fire season has not changed, implying that fire intensity has not increased. Fire frequency and population density were correlated, and it is suggested that fire suppression plays a critical role in offsetting potential impacts of increased ignitions. Large fires were found to not depend on old age classes of fuels, and it is thus unlikely that age class manipulation of fuels can prevent large fires. Expansion of the urban-wildland interface is a key factor in wildland fire destruction.

- **University of California at San Diego, California Applications Program (CAP).** Anthony Westerling et al. of the California Applications Program (CAP) at UCSD work on modeling and statistical forecasts of the 2003 Western wildfire season using canonical correlation analysis. Experimental forecasts for the 2003 fire season indicated that a low area would be burned in most western deserts and basins, a high area would be burned in the southern Rocky Mountains and at higher elevations in Arizona and New Mexico, and a mid to high area would be burned in the Sierra Nevada. This pattern—largely a continuation of that seen in 2002—is the result of persistent drought. If parts of the western United States experience significant additional precipitation before the start of the western fire season, high forecasts for mountain provinces could change, but low forecasts for basins and deserts are unlikely to be affected.

Extreme Events

- **Lawrence Berkeley National Laboratory (LBNL) and National Weather Service (NWS).** The Lawrence Berkeley National Laboratory, and Eric Strem of the National Weather Service's California-Nevada River Forecast Center conduct research on how climate change may bring more winter floods, and a drier growing season in California.

Air Pollution

- **University of California at Davis (UCD).** Various groups at UCD conduct research on aspects of air pollution. Information on different entities conducting research projects is available at: http://www.news.ucdavis.edu/sources/air.lasso.

- **University of California at Davis.** Jeremy Aw and Michael Kleeman from UCD research the temperature variability on urban air pollution. A short description of their work follows: The direct effect of intra-annual temperature variability on ozone and $PM_{2.5}$ concentrations at the urban scale was simulated using a high-resolution air quality model that tracks the temperature-dependant formation of secondary organic and inorganic aerosol components. Calculations show that the concentration of ozone and non-volatile secondary particulate matter will generally increase at higher temperatures, due to increased gas-phase reaction rates. The concentration of semi-volatile reaction products also will increase at higher temperatures, but the amount of this material that partitions to the particle phase may decrease as equilibrium vapor pressures rise. Calculations performed for Southern California on September 25, 1996 predict that intra-annual temperature variability may cause peak ozone and $PM_{2.5}$ concentrations to fluctuate by up to 16% and 25%, respectively. The 24-hour average $PM_{2.5}$ concentrations will decrease with increasing temperatures for inland portions of the South Coast Air Basin during most of the day. Slight increases in 24-hour average $PM_{2.5}$ concentrations were predicted for coastal regions. The majority of the predicted shift in $PM_{2.5}$ concentrations was related to increased production rates for nitric acid and condensable organic compounds balanced against increased volatilization of these products. Semi-volatile particulate ammonium nitrate concentrations are most sensitive to volatilization losses at hotter temperatures and when the ratio of gas-phase ammonia to nitric acid concentrations is approximately equal. Background sulfate particles and particles released from non-catalyst-equipped gasoline-powered engines, diesel engines, and food cooking were shifted to smaller sizes as ammonium nitrate volatilized at hotter temperatures.

- **University of California at Berkeley.** Robert Harley and others are conducting climate-related air quality research in California under the title of "Guiding Future Air Quality Management in California: Sensitivity to Changing Climate." The overall objective of this research is to assess the impacts of changes in climate on regional air quality in California. Sensitivity of tropospheric ozone will be quantified in response to changes in climate-sensitive processes such as photochemical reaction rates, biogenic emissions, anthropogenic emissions, pollutant boundary conditions, and surface deposition velocities. Additional analyses of relevant data will be used to describe process-level effects of climate-related variables. The overall effects and the process-level contributions of changes in each climate variable will be presented in a form similar to the IPCC presentation of radiative forcing terms and contributions due to greenhouse gases, direct and indirect effects of aerosols, and more.

  Their proposed research includes three major tasks: (1) air quality modeling in conjunction with online sensitivity analysis techniques, (2) process-level analysis of the impacts of climate-related variables on atmospheric chemistry, biogenic and anthropogenic emissions, and boundary layer meteorology, and (3) integration of the results of the first two tasks into an overall assessment of the impacts of climate change on air quality.

- **Scripps Research Institute, Department of Molecular and Experimental Medicine.** Sandra C. Christiansen et al. examine the exposure and sensitization to environmental allergen of predominantly Hispanic children with asthma in San Diego's inner city.

Infectious Diseases

- **The Centers for Disease Control and Prevention, the Mexican Secretariat of Health, and border health officials.** Cross-border movement has been identified as an important factor in the transmission of various diseases (infectious and emerging). Michelle Weinberg (Centers for Disease Control and Prevention) and others work on the Borders Infectious Disease Surveillance (BIDS) project, a surveillance system for infectious diseases along the U.S.-Mexico border. It was developed in 1997, when an active sentinel surveillance system was implemented for hepatitis and skin rashes accompanying fever. Improving bi-national communication systems and information-sharing proved to be crucial for the project's success. The BIDS project is sufficiently flexible to potentially expand into other borders, and incorporate other syndromes and diseases. Furthermore, it demonstrates that the development of a regional surveillance system for one of the world's busiest geographic boundaries is feasible. (See: www.cdc.gov/ncidod/EID/vol9no1/02-0047-G2.htm).

Airborne Infectious Diseases

Coccidioidomycosis (Valley Fever)

- **University of Virginia at Roanoke-Salem.** Dr. Edward L. Arsura et al. research climate controls on Valley Fever incidence in Kern County, California.
- **University of California at Irvine.** Charlie Zender et al. work on cocci of the association of age and mortality in general and in the immunocompetent (i.e., those capable of developing an immune response).
- **University of Arizona.** The Valley Fever Center for Excellence, at the University of Arizona, conducts research on cocci in endemic areas.
- **Centers for Disease Control and Prevention.** E. Durry et al. research the reemergence of a cocci, an endemic disease in California.
- **University of California at Irvine; University of California, San Diego School of Medicine; and the University of Arizona.** Cocci research is also conducted by Dr. Joseph Kim et al. at the University of California at Irvine, who look at chronic pulmonary cocci; and Dr. Theo N. Kirkland at the University of California, San Diego School of Medicine, who study cocci as a reemerging infectious disease. Modeling of cocci incidence on the basis of climate conditions as well as the relationship between cocci and environmental variability is conducted by Korine Kolivras et al. of the University of Arizona.

Kawasaki Disease

- **The California Applications Program (CAP) and the University of California at San Diego.** Kawasaki disease has become the most common cause of acquired heart disease in children. The California Applications Program is researching a possible link between climate and Kawasaki disease with a group led by Jane C. Burns, MD, Professor of Pediatrics with the University of California, San Diego. More information about the Kawasaki Disease Research Program can be found at http://meteora.ucsd.edu/cap/calif_health.html.
- **University of California, San Diego.** D. E. Bronstein et al. research the relationship of climate, ethnicity and socioeconomic status to Kawasaki disease in San Diego County.
- **University of California at Los Angeles, Mattel Children's Hospital.** Dr. Ruey-Kang R. Chang looked at the epidemiologic characteristics of children hospitalized for Kawasaki disease in California.

Vectorborne Infectious Diseases

- **California Department of Health Services (CDHS), members of the Mosquito and Vector Control Association of California (MVCAC), and the Center for Vector-borne Disease Research at University of California, Davis (UCD).** A statewide Encephalitis Virus Surveillance (EVS) program currently integrates the efforts of the CDHS, members of the MVCAC, and the Center for Vector-borne Disease Research at UCD. Weather data and water availability from scattered sources are monitored and interpreted locally by MVCAC personnel. Mosquito abundance is monitored by light and other traps by MVCAC. Virus activity in the bird cycle is detected by UCD (which tests pools of mosquitoes for infectious virus) and CDHS (which tests the blood of sentinel chickens for antibodies). Horse and human cases are detected by health-care providers who must recognize mosquito-borne viruses as the possible cause for the illness and request appropriate laboratory tests, which are conducted free by the CDHS. Mosquito abundance and virus activity is reported weekly by fax/e-mail to all participants and interested organizations by the CDHS.

- RESEARCH TOWARD A MODEL SYSTEM: Research upon which the current EVS system is based was largely completed in the 1960s. Although selected aspects have been improved since that time, there has been no focused effort to modernize the current system. In 1997, UCD launched a five-year research project targeting five areas of the EVS program. The project—which has received integrated financial support from selected MVCAC members, grants the

University-wide Mosquito Research Program, the CDC and NIH, and collaboration with MVCAC members and the CDHS—is focusing on the following areas:

1. **Human and horse cases.** Recent serological surveys indicate low-level annual infection of humans by SLE and to a lesser extent WEE, but clinical cases are detected and/or reported by health care providers, even from areas supporting elevated virus activity.
2. **Viral activity.** Minimal data is available to relate seroconversion rates in chickens and virus infection rates in mosquitoes to virus infection rates in wild bird populations. To facilitate detecting infection in wild birds, a new assay was developed that has allowed us to rapidly and inexpensively test any bird sera for any virus.
3. **Mosquito abundance.** Light traps currently are the method of measuring mosquito abundance; however, effectiveness has been compromised recently by increased levels of background illumination due to security lighting, expanded residential housing, and decreased mosquito abundance. Ongoing research plans to launch an Integrated Mosquito Sampling Program that combines several collection methods to enhance detection of important species in specific habitats.
4. **Analyses, prediction and reporting.** Current reporting consists of a weekly fax or email message listing human and horse cases, positive sentinel chickens, and virus isolations from mosquitoes during the previous week. There is no archival system. Interpretation and analyses largely are left to report recipients. In 1997, UCD and MVCAC developed a geographical information system to record sentinel chicken flock and mosquito pool collection locations, and integrated these data with mapping software into the World Wide Web (WWW) or Internet access. At a glance, the spatial pattern of virus activity is delineated at the state and local levels. Data also will be permanently archived and available on the Web to California, the U.S. government, and international agencies. The plan is to eventually interface this system with weather and water data and predictive models to "forecast" virus activity based on sensitive predictive variables.
5. **Weather and water.** Weather currently is recorded electronically at a series of remote California Irrigation Management Information System (CIMIS) and National Oceanographic and Atmospheric Association

(NOAA) stations. These data are managed at UCD with WWW access. Additional data on snowpack and agricultural irrigation are available but scattered. Plans to develop appropriate databases that interface with simulation models to express these data into terms of mosquito abundance, virus activity, and the risk of human and horse cases are under way.

- **Marin/Sonoma Mosquito and Vector Control District.** More information about vectorborne disease can be found at the Marin/Sonoma Mosquito and Vector Control District website (an excellent source of information): www.msmosquito.com/
- **California Applications Program (CAP).** CAP is researching links between climate and vector borne diseases with a group led by Bill Reisen, at the Arbovirus Research Station in Bakersfield, California. Working with Bill is Bruce Eldridge, Director of the UC Mosquito Research Program in the Department of Entomology at the University of California, Davis. Dr. Eldridge maintains a Web resource for mosquito and vector control in California at http://vector.ucdavis.edu/. The CAP initial analysis of Kern County Mosquitos is available at: http://meteora.ucsd.edu/cap/mosquito2.html.

- **The Center for International Earth Science Information Network (CIESIN).** The Center has developed an overview of models that predict changes in incidence of vectorborne diseases attributable to climate change. It is available at: http://infoserver.ciesin.org/TG/HH/veclev3c.html.

- **University of California at Berkeley (California Climate Change Center) and the California Applications Program (CAP).** William Reisen of the University of California at Berkeley and Dan Cayan et al. of CAP looks at the effect of temperature on *Culex tarsalis* (Diptera: Culicidae) from the Coachella and San Joaquin Valleys of California. The CAP and the CCCC aim to develop and provide better climate information and forecasts for decision makers in California and the surrounding region. By working directly with users, CAP and CCCC are working to evaluate climate information needs and utility from the user perspective. See http://meteora.ucsd.edu/cap/.

- **University of California at Davis.** Christopher Barker and others developed a mosquito surveillance plan, as described below: In order to provide a semi-quantitative means for assessing risk for WEE or SLE viruses, and to provide intervention guidelines for mosquito control and public health agencies during periods of heightened risk for human infection, the California Mosquito-Borne

Virus Surveillance and Response Plan was developed. West Nile virus recently arrived in California, and the response plan also will provide a baseline for assessing the risk for human and equine infection with this virus. In the response plan, overall risk is calculated by averaging risk due to: (1) environmental conditions, (2) adult mosquito vector abundance, (3) vector infection rates, (4) sentinel chicken seroconversion rates, (5) equine cases (for WEE), (6) human cases, and (7) the proximity of virus activity to populated areas.
Overall risk is categorized into three levels: normal season, emergency planning, or epidemic conditions.

- **University of California at Davis.** Jeny Wegbreit and William K. Reisen study the relationships among weather, mosquito abundance, and encephalitis virus activity in California.

- **California Applications Program (CAP).** CAP's contribution to the January 2002 MVCAC conference "Climate variability and encephalitis epidemiology" was: "Climate Linkages to Female *Culex Cx.* tarsalis Abundance in California" can be accessed through http://meteora.ucsd.edu/cap/mosq_climate.html.

West Nile Virus

- **University of California at Davis, Department of Entomology.** Laura B. Goddard et al. research the vector competence of California mosquitoes for West Nile virus.

- **U.S. Army Medical Research Institute of Infectious Diseases.** Mike Turell and others evaluate the vector competence of *Culex tarsalis* from Orange County, California, for West Nile virus.

Hantavirus Pulmonary Syndrome (HPS)

- **University of New Mexico.** James Mills et al. conduct HPS studies on reservoir populations in the Southwestern United States.

Waterborne Infectious Diseases

- **University of California at Irvine, UCI Environmental Health Science and Policy Program.** Ryan H. Dwight et al. study the association of urban runoff with coastal water quality in Orange County, California.
- **Pacific Institute for Studies in Development, Environment, and Security.** Peter Gleick, of the Pacific Institute for Studies in Development, Environment, and Security researches water issues and how they relate to climate change.

Other Health-Related Sectors

- **University of California at Berkeley, Center for Children's Environmental Health Research, School of Public Health.** Asa Bradman et al. investigate children's exposure to pesticides from California's Central Valley.

- **The University of Delaware.** Researchers look at killer bees and their progress in the United States.

- **University of Florida and Illinois State University.** Barry Alto (a doctoral student in entomology at the University of Florida) and Steven Juliano (a professor of biology at Illinois State University) are conducting research on how pests such as the Asian Tiger mosquito behave at different temperatures. If current warming trends continue, the range of some pests could be expanded. Juliano and Alto are conducting follow-up research at the Florida Medical Entomology Laboratory in Vero Beach as part of a project concerning invasion biology of the Asian tiger mosquito. The project is funded by the National Institutes of Health and involves researchers from the University of Florida, Illinois State University, Yale University, and Brazil's ministry of health.

- **Lawrence Berkeley National Laboratory (LBNL).** Dan Krotz of LBNL projects climate change's impact on California's watersheds.

- **University of California at Santa Cruz.** Tim Stephens of UCSC researches California's vulnerability to global warming.

- **Stanford University.** Jonathon Stillman examines the acclimation capacity that underlies susceptibility to climate change in California.

- **Intergovernmental Panel on Climate Change (IPCC).** Recognizing the problem of potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the IPCC in 1988. The IPCC is a major international scientific community effort on climate change (studies published in 2001). (www.ipcc.ch/index.html)

- Other entities working on the health impacts of climate change include the University of Maryland, Pennsylvania State University, University of Delaware, the Georgia Institute of Technology, Science Communication Studies, the National Oceanic and Atmospheric Administration (NOAA), NASA, the University of South Florida, the U. S. Department of Agriculture (USDA), University of Texas in Houston, and the New Orleans Mosquito Control Board (EHP 1999).

Appendix B
Health-Related Climate Change Publications

- "Climate Change in a Warming World." Gleick, Peter. *California Water News* 4 Jan. 2001.

- "Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulnerable region." Snyder, M. A., J. L. Bell, L. C. Sloan, P. B. Duffy, B. Govindasamy. *Geophys. Res. Lett.* 29(11), 10.1029/2001GL014431, 2002.

- *Global Environmental Outlook 3.* United Nations Environment Program (UNEP). This report, released in July 2002, reviews climate change impacts on the full range of global ecosystems, such as forests, oceans, fisheries, water resources, and more. The authors include a 30-year projection of likely impacts, based on four scenarios of policy frameworks. (www.unep.org/GEO/geo3/)

- *Global Climate Change: Potential Effects on the Sacramento/San Joaquin Watershed and the San Francisco Estuary.* Knowles, Noah, and Dan Cayan. Scripps Institute of Oceanography. 2001.

- Global Warming Could Make Water a Scarce Resource. Lazaroff, Cat. 15 December 2000. Environment News Service.

- *Global Warming to Affect Water Supply.* Perlman, David. 15 June 2001. CPR.

- "The Impacts of Climate Change on California's Water Resources: Recommendation for 'The California Water Plan'." Gleick, Peter. Pacific Institute for Studies in Development, Environment, and Security. 13 July 2001.

- *The Potential Consequences of Climate Variability and Change for California,* California Regional Assessment Group, USGCRP. Draft June 2002 (Bob Wilkinson). U.S. Environmental Protection Agency. www.usgcrp.gov/usgcrp/nacc/california.htm.

- *"Trends and Potential Effects of Global Warming on California Water Resources."* Roos, Maury. 13 July 2001.

- *U.S. National Assessment of the Potential Consequences of Climate Variability and Change.* U.S. Global Change Research Program (USGCRP). This work was initiated in 1997 to evaluate and synthesize available information about the potential impacts of climate change on the United States, to identify options for adapting to climate change, and to summarize research needs for improving knowledge about vulnerability, impacts, and adaptation (studies completed up to 2001). (www.usgcrp.gov/usgcrp/nacc/default.htm)

- *U.S. Climate Action Report: The United States of America's Third National Communication Under the United Nations Framework Convention on Climate Change.* U.S. Department of State. May 2002. This report issued recently by the Bush Administration, relies on findings from the IPCC and National Assessment studies to take a deeper look at climate change policy. This recent report is seen as a major step toward acceptance of global warming and climate change. (http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsUSClimateActionReport.html)

- *U.S. Geological Survey. Investigating Climate Change of Western North America.* USGS Fact Sheet. 19 June 1996. (marine.usgs.gov/fact-sheets/westclimate/)

Reports by Nongovernmental Organizations (NGOs)

- *Aquatic Systems and Global Climate Change - Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States.* January 2002. Prepared for the Pew Center on Climate Change.

- *Climate Change and the California Public's Health.* Tryzna. 2003. California Institute of Public Affairs. (A background paper for the Public Health Institute.)

- *Heat Waves and Hot Nights.* Physicians for Social Responsibility (PSR). 2000. (www.mit.edu/~donnan/CV/2000%20Ozone%20Action%20Heatwave%20Report.pdf)

- *Effects of Global Warming on Salmon and Trout in U.S. Streams.* Natural Resource Defense Council and Defenders of Wildlife. May 2002.

Pertinent Figures from Two Online Reports

***Hot Prospects: The Potential Impacts of Global Warming on Los Angeles and the Southland* (The EDF Report)**

The following from a report by the Environmental Defense Fund (EDF) illustrates some of the issues that are discussed in this roadmap. The report may be accessed through http://www.environmentaldefense.org/documents/494_HotProspects%2Epdf.

- EDF Figure 3-1: Sea-level rise projections for the Los Angeles area using model projections and current trends analyses.
- EDF Figure 3-3: Rainfall during February, 1998 and for the season compared to average rainfall for Santa Barbara, Los Angeles and San Diego.
- EDF Figure 5-1: Number of days above 90°F per year in Los Angeles for current average (base) and future decades (2020s, 2050s, and 2090s) using model projections and current trend analyses.
- EDF Figure 5-2: Number of heat waves (defined as three consecutive days at or above 90°F) per year in Los Angeles for current average (base) and future decades (2020s, 2050s, and 2090s) using model projections and current trend analyses.
- EDF Figure 5-3: Maximum duration of heat waves in number of days in Los Angeles for average (base) and future decades (2020s, 2050s, and 2090s) using model projections and current trend analyses.
- EDF Figure 5-4: Percentage change in peak ozone concentration occurring anywhere in the Los Angeles Basin with controlled emissions scenario and climate change scenarios.
- EDF Figure 5-5: Comparison of changes in peak ozone for controlled and non-controlled emissions scenarios with climate change occurring anywhere in the Los Angeles Basin using the CCGS (Canadian Centre with aerosols) model simulation for increased temperature.
- EDF Figure 5-7: Asthma hospitalizations in Los Angeles County by patient's zip code, 1996.
- EDF Table 5-1: Estimated total excess mortality for an average summer season for three climate change models, assuming full acclimation.

Heat Waves and Hot Nights. (Ozone Action and Physicians for Social Responsibility**).**
www.mit.edu/~donnan/CV/2000%20Ozone%20Action%20Heatwave%20Report.pdf)

- PSR figure: National heat stress days-average number of extreme days per year
- PSR figure: National heat stress nights-average number of extreme nights per year
- PSR figure: National heat waves-average number of heat waves per year
- PSR figure: Heat stress days-number of extreme days per year in San Francisco, CA, from 1948 to 1999.

Summaries of Two Reports of Particular Significance to This Roadmap

***Global Climate Change and California: Potential Implications for Ecosystems, Health and the Economy.* August 2003. Prepared for the California Energy Commission by the Electric Power Research Institute (Report P500-03-058CF).**

This report addresses the potential impacts of climate change on various sectors of the natural environment and the economy. It examines changes in terrestrial vegetation and the implications of these changes for both biodiversity and timber production; the potential impacts on water resources and agriculture (runoff, water resources, crop yields, and irrigation demands); and the potential impacts on energy and coastal resources.

The impacts of climate change on California are complex indeed. There could be increases in floods or droughts; increased energy costs; decreased water deliveries, particularly to agriculture, aquatic ecology and hydropower; damages to the coastline and increased costs for protecting coastal resources; loss of biodiversity; and long-run declines in timber production. On the positive side, crop yields could increase overall and timber supply could increase in the short run; both would benefit consumers.

This work examines a broad array of potentially affected sectors as well as the interactions between climate change and increased population, economic growth, and technological change. It considers a wide range of climate change scenarios, ranging from warmer and much wetter to warmer and much drier, as well as a wide range of socioeconomic scenarios. The ultimate goal of the studies is to identify key sensitivities of California's natural and economic systems to climate change.

Impacts on human health will be very sensitive to changes in climate variability. This report reviews an initial study of the historical relationship between climate variability and health in California, yet how future climate change may affect human health is not addressed in this report. Climate variability could affect the incidence and distribution of weather-sensitive diseases. Weather and climate variability are known to be directly associated with health effects such as heat stroke and illness, injuries, and deaths that occur during or following extreme weather events. Other adverse health effects—such as morbidity and mortality related to air pollution and illnesses associated with water-, food-, and vector-borne microorganisms—are indirectly related to weather and climate. In addition, many infectious diseases are affected by weather patterns and climate variability. In this study, time-series regression techniques were used to examine the relationship between weather patterns and hospital admissions for viral pneumonia, cardiovascular diseases, and stroke. Specific weather factors varied across geographic regions. It is suggested that it may be possible to reduce the impact of climate variability on health by using adaptive measures.

National Assessment: State of California
***Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change.* USGCRP. 2001.**
This report presents an overview of potential implications of climate change for California and summarizes, based on our present knowledge, what might be in store in the future.

The State of California has the largest population, the greatest diversity of people and environments, and the largest economy in the nation. Therefore, the changing climate poses significant implications for California's people, places, and valuable systems and resources.

The IPCC assessment indicates that the implications of global warming will manifest as an increase in average global temperatures, greater extremes of drying and precipitation, sea level rise, glaciers melting, and weakening of ocean circulation.

Among the findings of the report are: (1) the need for improved models to accurately represent and predict changes at a regional scale and learn more about the dynamics of climate change; (2) to restore and protect the environment while remaining economy-conscious; and (3) to forge new partnerships between business, government, and communities for a successful climate change response measure.

Climate change and variability will potentially affect precipitation in terms of timing, amounts, and form—as well as quality and uses. Extreme weather events, such as droughts, floods, and wildfires will likely become more frequent. The interconnected, complex set of infrastructure systems that supports California (e.g., transportation, communications, electricity) will be affected by a changing climate. All ecosystems (plants and animals) will be altered, and wildlife will have to adapt to changing habitats. It is noteworthy to point out that the impact areas are so linked that one affected sector will influence virtually every other sector. Similarly, climate change will have its effects, both direct and indirect, on human health. Direct effects include: floods, landslides, heat waves and fires; whereas, indirect effects include infrastructure damage which would impact sanitation and air quality, with increases in ozone concentrations.

As already mentioned, economy, infrastructure and natural systems are inextricably linked in California, and a clear understanding of the dynamics of these systems is imperative for the development of informed and systematic response and adaptive strategies.

Recommendations for future research consists of better understanding the dynamics of climate change and *sensitivity* to change, *capacity* to change or adapt, and *vulnerability* to change.

Overview of Publications Addressing Health-Related Climate Change Issues

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Heat Waves and Wildfires						
Oechsli et al. 1970. Excess mortality associated with three L.A. September hot spells.	Temperature	Los Angeles, September, hot spells.	Review	Heat-related excess mortality	The proportionate increase in mortality resulting from excessive heat increases progressively both with age and with temperature.	Maximum temperature is the single meteorological variable with the greatest predictive value for excess mortality.
Kalkstein and Green. 1997. An evaluation of climate /mortality relationships in large U.S. cities and the possible impacts of a climate change.	Temperature	44 large U.S. cities with metropolitan areas exceeding 1 million in population	Statistical (regression analysis)	Climate-related mortality	Data suggest an increased mortality related to climate change.	A sizable net increase in weather-related mortality is estimated if the climate warms as models predict.
Dessai, S. 2002. Heat stress and mortality in Lisbon part I. Model construction and validation.	Temperature	Lisbon. June-August. 1980–1998	Empirical-statistical model. Regression analysis.	Increased mortality	The mean annual heat-related mortality for the period 1980–1998 was between 5.4 and 6 deaths per 100,000.	Global climate change will have direct impacts on human health, including increased mortality due to heat stress and heat waves.
Smoyer-Tomic and Rainham. 2001. Beating the heat: development and evaluation of a Canadian hot weather health-response plan.	Humidex (heat stress index) Apparent temperature	Toronto, Ontario, between 1980 and 1996	Statistical	Heat-related excess mortality	Mortality rates for all age groups rose with increasing humidex and apparent temperature, with no significant increase for the people < 65 years. Excess mortality occurred as low as the 30°C –35°C humidex range. 32 excess deaths would be expected during a hot summer, and 34 fewer deaths would be expected during a cool summer.	In the event of a warming climate, more days with dangerously high humidex levels are likely to occur, and summer deaths are expected to increase. Toronto's hot weather health-response plan is an important early step for adaptation to climate change
van der Leun, and de Gruijl. 2002. Climate change and skin cancer.	UV radiation Temperature	Review	Analytical	Increase in incidence of skin cancer	It is becoming clear that the depletion of the ozone layer and climate change by the increasing greenhouse effect are interlinked in several ways.	It is likely that the baseline incidence of skin cancer will be augmented by rising temperatures.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Heat Waves and Wildfires (cont.)						
Torn et al. 1998. Will Climate Change Spark More Wildfire Damage?	Temperature Precipitation Wind speed humidity	Santa Clara, Amador El-Dorado, and Humboldt in CA. Simulations of 700 actual fires.	Modeling (GCM)	GCM output (fire outcomes)	Under climate change, Santa Clara and Amador-El Dorado will become warmer, windier, and drier, while Humboldt will become warmer, but less windy and more moist. The effect of climate change on wildfire severity can be expected to vary geographically. Under current climate conditions, escapes are rare. Between 1961 and 1997, only 0.03% to 0.5% of CA's wildfires escaped. But, the likelihood of damage from an escape is huge. Modeling results showed that the most severe effects of global climate change were inflicted on the Sierra foothills where the predicted number of potentially catastrophic fires increased by 143% in grassland and 121% in chaparral. In the Santa Clara area, contained fires in grass and brush burned 41% and 34% more area respectively, and the number of escaped wildfires increased by 53% and 21% in grassland and brush respectively.	The effect of climate change on fire starts was not a major issue since > 90% of fires in CA are started by people. Climate change will cause fires to spread faster and burn more intensely in most vegetation types. The biggest impacts will affect grassland where fires spread rate is fastest. Over all vegetation types, the predicted global warming will result in faster fires (and fewer slow ones) in the 2 more southerly areas. Rural areas with fewer fire suppression resources were at a greater risk of being subject to climate change-related fires. There are links between climate change and wildfires, and as humans continue to contribute to increasing the greenhouse gases, so will the danger of fires. Increases in wildfires in CA will most likely result in serious consequences for the residents and their property.
Davis et al. 1995. Sensitivity of chaparral ecosystems to global climate change.	Temperature	Los Padres National Forest, Central Coast, California	Modeling analysis	Frequency, spread, occurrence of wildfires	For temperature increases of 2°F and 8°F fire interval would decrease. Spring rainfall would offset all the increase for the 2°F and some for the 8°F.	Total area burned would grow. Interval between fires would decreases significantly.
CDC 2001 U.S. Trends and Summary of heat-related deaths rates in Los Angeles.	Temperature	1979–1998; CA, Los Angeles County, national mortality data	Statistical	Heat-related mortality	The age-adjusted heat-related mortality was 44% lower than that in the general population.	LA residents > 65 years were more likely than those < 65 to die from heat excess. Men were more likely than women, and blacks more likely than whites to die from exposure of excessive heat.
Keeley et al. 1999. Reexamining fire suppression impacts on brushland fire regimes.	California shrubland wildfires	California Statewide Fire History Database, since 1910	Analytical	Fire size, frequency, season, suppression	Data showed that, since 1910, fire frequency and area burned have not declined, and fire size has not increased. Fire rotation intervals have declined, and fire season has not changed, implying that fire intensity has not increased. Fire frequency and population density were linked. Large fires were not dependent on old age classes of fuels, and it is thus unlikely that age class manipulation of fuels can prevent large fires.	CA shrubland wildfires are destructive, and the problem has been intensified by fire suppression, leading to larger, more intense wildfires. It is suggested that fire suppression plays a critical role in offsetting potential impacts of increased ignitions. Expansion of the urban-wildland interface is a key factor in wildland fire destruction.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Heat Waves and Wildfires (cont.)						
Keeley, J. E. 2002. Fire management of California shrubland landscapes.	Temperature Fire	California shrubland landscapes	Analytical	Fire reduction	A major contributor to increased fire suppression costs and increased loss of property and lives is the continued urban sprawl into wildlands naturally subject to high intensity crown fires.	Fire management should focus on strategic placement of prescription burns to both insure the most efficient fire hazard reduction and to minimize the amount of landscape exposed to unnaturally high fire frequency.
Naughton et al. 2002. Heat-related mortality during a 1999 heat wave in Chicago.	Heat	Summer of 1999. Chicago. 63 case patients and 77 control patients.	Statistical, multivariate analysis	Heat-related mortality	Strongest risk factor for heat-related mortality was living alone (OR=8.1) and not leaving home (OR=5.8). The strongest protective factor was a working air conditioner (OR=0.2).	A working air conditioner is the strongest protective factor against heat-related deaths. Social isolation and old age are important risk factors. Education targeted to at-risk populations may decrease mortality within these groups.
Extreme Events						
Dwight et al. 2002. Association of urban runoff with coastal water quality in Orange County, California.	Precipitation	Southern California beaches	Statistical temporal and spatial analysis	Bacterial levels	Data show beaches next to rivers had the highest bacterial levels in both wet and dry seasons. Rainfall was significantly associated with water discharged from rivers which in turn was significantly associated with bacterial levels.	Swimming at beaches near rivers may pose a significant public health risk. The strong association found between precipitation and water pollution may be relevant to studies of potential health effects associated with climate change.
NASA. 2003. Climate changes may increase extreme rain/snow events in California.	CO_2 Temperature precipitation	California	Computer models	Increase in heavy precipitation and flooding	The Sierra Nevada region may experience substantial increases in heavy precipitation (> 2 inches of rain/day), and extreme precipitation events (> 4 inches of rain/day). Most of these increases occur during the winter (wettest season in the region). Data showed that heavy events of precipitation increased by 10–15 days/year.	Under climatic change, extreme events rose from 0.1% of wet days/year to 1% for all major CA basins. Elevation where freezing occurs will rise with temperature, i.e. most of the snow will come as rain. This could lead to a greater frequency of flooding.
Air Pollution						
Corbett, S. W. 1996. Asthma exacerbations during Santa Ana winds in Southern California.	Santa Ana winds	Southern California ER visits for asthma during a 4-year period.	Statistical analysis	Incidence of asthma	ER visits for asthma increased (3.12 vs. 2.16 visits/day) during Santa Ana winds vs. other weather conditions. Asthmatics appeared to be more ill, and showed higher admission rates (21.9% vs. 18.7%). The winds were also associated with lower counts of PM.	An unidentified factor associated with Santa Ana winds may be a stimulant for asthmatics and may increase ER visits for asthma.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Air Pollution (cont.)						
Cifuentes et al. 2001. Assessing the health benefits of urban air pollution reductions associated with climate change mitigation (2000-2020): Santiago, Sao Paulo, Mexico City, and New York City.	Ozone Particulate matter	Santiago, Sao Paulo, Mexico City, and New York City. 2000–2020	Statistical (multivariate methods, Poisson models)	Mortality and morbidity: avoidable premature deaths. Chronic bronchitis	Lessening fossil fuel emissions over the next 2 decades will reduce PM and O_3 and avoid approximately 64,000 premature deaths, 65,000 chronic bronchitis cases and 3 million person-days of work loss. Synergies were detected between air pollutants and allergens.	GHG mitigation can provide considerable local air pollution-related public health benefits by reducing fossil fuel combustion. Air pollution mapping for the South Coast basin of California estimated that 1,600 lives would be saved if ambient air pollution standards were attained.
Bobak, M. 2000. Outdoor air pollution, low birth weight, and prematurity.	SO_2 TSP NO_X	Live births registered by the Czech national birth register in 1991. Analysis of maternal exposures to pollutants.	Logistic regression	Adverse birth outcomes: low birth weight, prematurity, intrauterine growth retardation.	Low birth weight and prematurity were associated with SO_2 and to a lesser extent with TSP. In the first trimester, and for a 50µg/m³ increase in SO_2 and TSP, the adjusted OR for low birth weight were 1.2 and 1.15 respectively; for prematurity, the OR were 1.27 and 1.18.	Air pollution can affect the outcome of pregnancy and may increase the risk of adverse birth outcomes.
McConnell et al. 2002. Asthma in exercising children exposed to ozone: a cohort study.	O_3 PM_{10} NO_2	Southern CA. non-asthmatic children age 9–16 playing sports	Statistical: a cohort study	Development of asthma	In communities with high [O_3], the RR of developing asthma in children playing 3 or more sports was 3.3 (95% CI 1.9-5.8)	Air pollution and outdoor exercise could contribute to the development of asthma in children.
Peters et al. 2001. Increased particulate air pollution and the triggering of myocardial infraction.	Particulate matter	772 patients with MI in the greater Boston area, Jan.–May, 1996.	Case-crossover, multivariate statistical analysis.	Increased hospital admissions for CV diseases	The risk of MI onset increased in association with elevated concentrations of fine particles. Participants showed a 50% increase in heart attack risk in the 2 hours following exposure to high levels of fine particles. A delayed response associated with an increased 24 hours after exposure to high levels of fine particles was observed.	Brief exposures—as little as 2 hours, and 1 day after exposure—to elevated concentrations of fine particles in the air may temporarily increase the risk of heart attack, particularly among people already at risk for heart disease. Further studies are needed to clarify the importance of preventable MIs.
Friedman et al. 2001. Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic games in Atlanta on air quality and childhood asthma.	O_3 concentration Particulate matter	Children aged 1 to 16 years in metropolitan Atlanta during the 17 days of the Olympic games (July19–Aug. 4, 1996)	Ecological study ; multivariate regression analysis.	Asthma events	Asthma events decreased during the Olympic Games, and peak daily [O_3] decreased 27.9%. Alternative transportation policies reduced vehicle exhaust and related air pollutants by about 30%, the number of acute asthma attacks and Georgia Medicaid claims fell by 40% and pediatric emergency admissions dropped 19%.	Decreased traffic, especially during the critical morning period is associated with a prolonged reduction in O_3 pollution and significantly lower rates of childhood asthma events. Efforts to reduce air pollution and improve health via reductions in motor vehicle traffic should be supported.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Air Pollution (cont.)						
Cifuentes et al. 2002. Hidden health benefits of greenhouse gas mitigation.	GHG emissions	Building upon studies conducted in developing and developed countries.	Review	Mortality and morbidity	The more GHG abatement a country achieves by reducing fossil-fuel combustion, the more air pollution reduction-related health benefits will accrue.	Should the public health impacts become more recognized and integrated with climate policy, then funding and adoption of more efficient, less polluting technologies would be encouraged.
Samet et al. 2000. Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994.	PM_{10} O_3; CO SO_2; NO_2	20 of the largest cities and metro-politan areas in the U.S. from 1987–1994.	Statistical regression model with pooled data	Daily mortality rates	Each 10µ/m³ increase in PM_{10} corresponded to 0.51% increase in the relative rate of death from all causes, and 0.68% increase in the relative rate of death from CV and respiratory diseases.	There is consistent evidence that the levels of fine PM in the air are associated with the risk of death from all causes and from CV and respiratory illnesses.
Ziska et al. 2003. Cities as harbingers of climate change: common ragweed, urbanization, and public health.	Temperature Carbon dioxide	Urban and rural areas	Mathematical	Qualitative and quantitative aspects of ragweed growth/ pollen production	For 2000 and 2001, average daily values of [CO_2] and air temperature within an urban environment were 30% to 31% and 1.8°C to 2.0°C higher than those at a rural site. Ragweed grew faster, flowered earlier, and produced greater pollen at urban relative to rural locations.	Air temperature and atmospheric CO_2 (two aspects of future global environmental change) are found to be significantly higher in urban relative to rural areas.
Griffin et al. 2001. African desert dust in the Caribbean atmosphere.	Dust	Air samples taken from U.S. Virgin Islands during both normal atmospheric conditions and African dust events.	Mathematical	Cultivatable microbiological analysis for the presence of fungi and viable bacteria	During African dust events, the number of airborne microorganisms can be 2 to 3 times that found in clear atmospheric conditions. Large dust events have been reported to impact approximately 30% of the U.S. landmass.	Dust may serve as a medium for the global transport of microorganisms. Exposure to desert dust has been identified as the source of a number of public health threats such as cocci in humans, silicosis, allergic reactions, asthma, as well as cistern contamination.
Ahlholm et al. 1998. Genetic and environmental factors affecting the allergenicity of birch pollen.	Temperature Pollen	Mountain birch pollen samples collected at Kevo subarctic research station in June 1996.	Statistical-ANOVA	Quantitative measurement of allergens	Samples collected from sites with higher daily mean temperature had higher allergen content. Both genetic and environmental factors have an effect on the allergen content.	An increase in temperature due to climate change may affect the allergenicity of pollen, and thus the prevalence of allergies. More research is needed to confirm results in other allergen-containing plants.
Barnes et al. 2000. The effect of temperature, relative humidity, and rainfall on airborne ragweed pollen concentration.	Temperature Precipitation Wind speed	Air samples collected on top of a 5-story building in Kansas City	Analytical mathematical	Ragweed pollen counts	Data showed highest pollen counts at noon and lowest at 6:00 p.m.	Heavy rain always lowered pollen counts (rain usually did). The passing of major weather fronts and the associated temperature drops, wind disturbances and rainfall are the major factors influencing ragweed pollen counts.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Air Pollution (cont.)						
Larsen, L. C. 2001. An assessment of the impact of California's Phase 2 Reformulated Gasoline on ozone air quality.	O_3 concentration Air temperature Wind velocity	Daily regional measurements of O_3 in 3 California areas	Regression analysis	$[O_3]$	O_3 benefits attributed to CA RFG are 8%–13% in the LA area, 2%–6% in the San Francisco Bay Area, and 3%–15% in the Sacramento area.	CA's Phase 2 RFG, introduced early in 1996, represents an important step toward attainment of O_3 standards. Studies of vehicle emissions and ambient air quality data have reported substantial reductions of O_3 precursors due to RFG.
Wayne et al. 2002. Production of allergenic pollen by ragweed *(Ambrosia artemisiifolia L.)* is increased in CO_2-enriched atmospheres.	CO_2 concentrations	In environmentally controlled greenhouses, ragweed plants	Statistical	Stand-level total pollen production and end-of-season measures of plant mass, height, and seed production.	A doubling of the atmospheric CO_2 concentration simulated ragweed-pollen production by 61% ($p=0.005$).	There may be significant increases in exposure to allergenic pollen with global warming. Further research may allow more accurate evaluations of the future risks of hay fever and respiratory diseases (asthma) exacerbated by pollen.
Gent et al. 2003. Association of low-level ozone and fine particles with respiratory symptoms in children with asthma.	Ozone; PM ≤ 2.5 µm	271 asthmatic children up to 12 years in southern New England exposed to O_3 and $PM_{2.5}$ from April thru September 2001.	Logistic regression analysis	Respiratory symptoms; rescue medication use	O_3 but not $PM_{2.5}$ was significantly associated with respiratory symptoms and rescue medication use among those using maintenance meds. A 50 ppb increase in O_3 corresponded to 35% of wheezing and 47% chest tightness.	Even at low levels of ambient ozone, and controlling for ambient fine particle concentration, children with severe asthma using maintenance medication are particularly vulnerable to O_3 and are at a significantly increased risk of experiencing respiratory symptoms.
Aw and Kleeman. 2003. Evaluating the first-order effect of intra-annual temperature variability on urban air pollution.	Ozone Temperature $PM_{2.5}$	The South Coast Air Basin, in the Los Angeles area	Analytical (using an air quality model CIT/UCD)	Effects of temperature variability on O_3 and $PM_{2.5}$	The direct effect of inter-annual temperature variability can change peak O_3 and 24 hr average $PM_{2.5}$ by 16% and 25%, respectively, when other meteorological variables and emissions patterns are held constant.	[O3] and non-volatile secondary PM will generally increase at higher temperature, due to increased gas-phase reaction rates.
Neidell. 2001 Air pollution, health, and socio-economic status: the effect of outdoor air quality on childhood asthma.	Sulfur dioxide Carbon monoxide	CA. 1992–1998 hospital discharges for children under 18 years of age.	Statistical (time series)	Child hospitalizations for asthma	SO_2 had a significant effect on asthma hospitalizations for infants. CO increases hospitalizations among children 1 to 18. The decline in CO from 1992–1998 explains 9%–14% of the decrease in asthma hosp. rates, which in 1998, in CA alone saved about $5.6 million.	The net effect of pollution is much greater for children of lower SES. Pollution is one mechanism through which SES impacts health. Pollution effects vary by child's age. Health advisories decreased asthma hospitalizations 4%–7%

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Air Pollution (cont.)						
de Gruijl et al. 2003. Health effects from stratospheric ozone depletion and interactions with climate change.	UVB radiation	Animal models	Epi and experimental studies.	Cancer; cataracts; weakening of the immune system.	UV radiation is a definite risk for certain types of cataracts. There is a causal link between squamous cell carcinoma and cumulative solar exposure. UV exposure at a very young age is more detrimental than exposure in adulthood. It is of concern that the immune system response to vaccination could be depressed by UVB exposure.	Interactions between climate change and ozone depletion further complicate human health risk assessments but might result in an increased incidence of cataracts and skin cancer, plus alterations in the patterns of certain categories of infectious and other diseases.
Kinney et al. 1991. Associations of daily mortality and air pollution in Los Angeles County.	Total oxidants (Ox); SO_2; NO_2; CO; KM; T; relative humidity (RH); extinction coefficient (Bext)	Los Angeles County, California. 1970–1979	Multiple regression analysis	Air pollution-related mortality	NO_2, CO, or KM (particulate optical reflectance measure) were strongly associated with daily mortality. They are also highly correlated with one another, making it impossible to discern each one's individual impact on the outcome (air pollution-related mortality)	Study results show that small but significant associations exist in Los Angeles County between daily mortality and 3 separate environmental factors: temperature, vehicle-related pollutants (CO, KM, NO_2), and photochemical oxidants.
Zablocki. 2000. Air pollution linked to heart problems, deaths.	Ozone Particulate matter	21 people, monitored for heart rate while exercising	Analytical	Heart rate variability	On days with high levels of fine particles and O_3, the subjects showed reduced heart rate variability.	Air pollution hinders the heart's ability to adjust to the pumping demands the body puts on it.
Infectious Diseases						
Durry et al. 1997. Coccidioidomycosis in Tulare County, California, 1991: Reemergence of an endemic disease.	Rainfall	South Central Tulare County, California	Statistical multivariate analysis	Excess cases of coccidioido-mycosis	South Central Tulare County had the highest cocci attack rate. 27% of case-patients were hospitalized. Male sex (RR) 2.5, black people and Asian races (RR 4.8), and age $\geq$ 20 years (RR 8.3) were statistically significant.	The cocci outbreak was preceded by an unusually rainy spring. Dust reduction measures during cocci outbreaks can help reduce exposure.
Chang, R. K. 2002. Epidemiologic characteristics of children hospitalized for Kawasaki disease in California.	Temperature Precipitation	Children 0 through 17 years old who had a discharge diagnosis of KD; California	Multiple regression analysis	KD incidence	Compared with 1995 and 1996, KD incidence for children < 5 years old increased by 30% in 1997 and 1998, but remained unchanged for children 5 to 9. Asians had the highest incidence of 35.3 cases/100,000 children < 5 years old, followed by blacks (24.6) and whites (14.7). Cases peaked in March and had its nadir in September.	KD incidence was not associated with temperature, precipitation, family size or population density.
Bronstein, D. E. 2000 Relationship of climate, ethnicity and socioeconomic status to Kawasaki disease in San Diego County, 1994 through 1998.	Temperature Rainfall	Children < 5 years of age from all ethnic backgrounds	Statistical	KD incidence	The KD incidence in children < 5 years ranged from 8.0 to 15.4/100 000. It was inversely associated with average monthly temperature and positively associated with average monthly precipitation. Asian/Pacific Islanders were at increased risk (rate ratio, 2.14) for KD relative to all other ethnic groups combined.	The skewed ethnic distribution and seasonality of KD are consistent with the hypothesis that it is an infectious disease that is influenced by environmental and genetic factors.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Eisen et al. 2002. Seasonal activity patterns of *Ixodes pacificus* nymphs in relation to climatic conditions.	Temperature Rainfall	*I. Pacificus* nymphs in California	Statistical analysis (linear regressions)	Nymphal densities	The lengths of the periods with nymphal densities exceeding recorded yearly peaks in the woodlands were positively associated with rainfall and negatively with maximum air temperatures during April–May. In oak/madrone woodland, nymphal densities typically started to decline when mean maximum daily air temperatures exceeded 23°C. Nymphal densities were higher in dry oak/madrone relative to moist redwood/tanoak woodland from mid-March to late May 2000, similar in both habitat types in early June, but higher in redwood/tanoak woodland from late June onwards.	Large-scale studies of the density of *I. pacificus* nymphs in California need to consider spatial variation in the length of nymphal activity periods and select temporal sampling regimens that yield representative data for all habitat types.
Reeves et al. 1994. Potential effect of global warming on mosquito-borne arboviruses.	Temperature	*Culex tarsalis* Coquillett in 2 regions where Temperature differed by 5 degrees C.	Mathematical	Survival of mosquitoes; Extrinsic incubation times	Daily mortality of adult vectors increased by 1% for each 1°C increase in temperature	With global warming, North America could become more receptive to invasion by tropical vectors and diseases. Geographic distribution of vector, human, and animal populations could be altered.
Lobitz et al. 2000. Climate and infectious disease: use of remote sensing for detection of *Vibrio cholerae* by indirect measurement.	Water temperature Nutrient conc. Plankton production	Remote sensing data for the Bay of Bengal were compared with cholera case data collected, 1992–1995 in Bangladesh.	Mathematical	Bacterium *V. cholerae.*; sea surface height; sea surface temperature	Sea surface temperature and height were found to be correlated with cholera outbreaks.	There is strong evidence that cholera epidemics are climate-linked.
Williams et al. 1979. Symptomatic coccidioido-mycosis following a severe natural dust storm. An outbreak at the Naval Air Station, Lemoore, CA.	Dust (TSP counts)	Southeast CA. 26,000 residents of San Joaquin valley with access to healthcare at Naval Hospital, Lemoore, California.	Mathematical	Valley fever (cocci) incidence	18 new cases of symptomatic cocci were detected 2 to 4 weeks following the storm.	A direct temporal relationship between dust storms and increased incidence of cocci was found. Data suggest that non-whites may be more susceptible to acquiring and developing the disease.
Schneider et al. 1997. A coccidioidomycosis outbreak following the Northridge, California earthquake.	Earthquake; Dust (arthrospores)	Ventura County, CA; Jan.–March 1994; 203 outbreak - associated cocci cases	Epi investigation: Population-based case-control study	Cocci cases	Disease onset for cases peaked 2 weeks after the earthquake. The attack rate was 2.8 times greater for people ≥40 years old. Being in a dust cloud (OR=3.0) and time spent in a dust cloud ($p<0.001$) significantly increased the risk of being diagnosed with acute cocci.	Data suggest that earthquakes may be implicated in cocci outbreaks. During brief and transient dust-generating events (e.g., an earthquake, or a dust storm in an endemic area) avoidance of dust clouds or areas of heavy dust may be beneficial.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Kirkland and Fierer. 1996. Coccidioidomycocis: a reemerging infectious disease.	Climatic and demographic factors	Kern County, CA	Research paper/ descriptive	Increase in cocci incidence	The airborne dust associated with landslildes triggered by the earthquake was implicated in the higher cocci incidence. Pregnant women, the immunosuppressed, blacks and Filipinos are at high risk for developing cocci. There was an increase in cases from the 1980s to 1991–1993.	Dust storms are frequently followed by outbreaks of cocci. Factors that account for increases in incidence include the weather and a high number of susceptible people in the endemic area.
CDC. 1994. MMWR. Emerging infectious diseases-update: cocci-CA, 1991–1993.	Dust / infective arthroconidia	Cocci occurrence in Kern County, San Joaquin valley, CA, 1991–1993	Summary	Cocci incidence	In 1991, there were 1,200 cocci cases (annual average=428), 4,516 cases in 1992, and 4,137 in 1993.	Factors associated with the cocci outbreak were weather conditions (drought followed by heavy rains) as well as a larger susceptible population.
CDC. 1996. MMWR; Cocci-Arizona, 1990–1995.	Drought Precipitation Temperature	Arizona; 1990–1995/ cases of cocci	Statistical	Cocci incidence	A substantial increase in cocci incidence was observed: 255 cases in 1990 up to 623 in 1995. Cocci disproportionately affected persons > 65 years and those infected with HIV.	Climatic factors may have played an important role in the increase in cocci incidence in Arizona.
CDC. 2000. MMWR; Cocci in travelers returning from Mexico–PA, 2000.	Dust	Travelers returning from Mexico after construction work that involved extremely dusty conditions; PA. 2000.	Cohort study	Serum specimens positive for *C. immitis*, indicating cocci infection	27 of the 35 travelers complained of flu-like symptoms; 27% met the definition for CM	Cocci outbreaks occur when susceptible people are exposed to airborne arthroconidia from events such as natural disasters, storms, and earth excavations.
Abbott et al. 1999. Long-term Hantavirus persistence in rodent populations in Central Arizona.	Precipitation; habitat structure	Central AZ, 1995–1996. 844 rodents	Longitudinal study	Hantavirus antibody Changes in rodent population; prevalence and incidence of hantavirus	Transmission of hantavirus was bimodal and associated with spring and autumn reproductive activity. Horizontal transmission may increase during the more active seasons.	Precipitation, habitat structure, and food resources influenced population dynamics, viral transmission and hantavirus persistence.
CDC. 2003. MMWR; Increase in coccidioidomycosis-Arizona 1998–2001	Drought indices (Palmer z, Palmer drought severity); wind velocity; mean temperature; dust; rain	Random sample of patients with cocci	Cohort study-Poisson regression	Evaluation of host factors, exposures and outcomes.	A high correlation (r2=0.75) between incidence of disease and rain, temperature, and dust months prior to the outbreak was observed.	The recent Arizona cocci epidemic is attributed to seasonal peaks of incidence that may be related to climate. Peak periods of cocci incidence occurred during the winter.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Mills et al. 1999. Long-term studies of hantavirus reservoir populations in the Southwestern U.S.: A synthesis.	Environmental variables	Reservoir mice populations in the southwestern U.S.	Longitudinal	Hantavirus antibody	Data suggested a higher prevalence of infection in older mice.	Findings were consistent with horizontal transmission. Prevalence of hantavirus antibody showed seasonal and multiyear patterns.
Cayan et al. 2003. Climate linkages to female *Culex Cx tarsalis* abundance in California.	Precipitation; snow water content-moisture indices.	Female *Cx. tarsalis* periods of 1973–2000; 1986–2000; 1954–2000. California Central valley.	Statistical time series	*Cx. tarsalis* females abundance	*Cx. tarsalis* abundance peaked in the summer between June and September.	Prior season moisture indices may be useful predictors of summer mosquito abundance. Strong correlations were detected between mosquito abundance and summertime.
CAP. 2003. Kern county mosquitoes-initial analysis.	PDSI, air temperature and precipitation	Female *tarsalis* mosquitoes in southern San Joaquin Valley.	Time series	Mosquito abundance	A large interannual variability was found. Abundance was strongly correlated with precipitation and PDSI. Higher temperatures in winter had some tendency to associate with higher abundances.	Data suggest that outbreaks of encephalitis are associated with climate variables such as precipitation, PDSI, and temperature
Pappagianis. 1994. Marked increase in cases of coccidioidomycosis in CA: 1991,1992, and 1993.	Precipitation	Southern San Joaquin Valley counties of Kern and Tulare; 1991 through 1993.	Mathematical	Number of infectious arthroconidia; cases of cocci.	The usual 5%–7% rate of pulmonary dissemination was noted in the cocci outbreaks, and cases similar to acute respiratory distress syndrome had been noted infrequently in previous outbreaks and were unusual in 1991 and 1992.	Factors thought to contribute to the unusual cocci increases were a drought of 5–6 years long; heavy rain in 1991 and 1992; building construction; and new susceptible individuals in endemic areas.
Kolivras and Comrie. 2003. Modeling valley fever (cocci) incidence on the basis of climate conditions.	Temperature Precipitation	Prima county, AZ	Exploratory analyses (multivariate analyses).	Incidence cases of cocci	Months with high incidence can be predicted more accurately than months with low incidence. Moderate model accuracy (r2 values for the monthly models: 0.15-0.50).	Models were developed to describe relationships between valley fever incidence and climate conditions and variability.
Leake et al. 2000. Risk factors for acute symptomatic coccidioido-mycosis among elderly persons in AZ, 1996–1997.	Dust (TSP)	Elderly ≥ 60 in Arizona between 1990 and 1996	Retrospective case-control studies	Incidence cases of cocci	Elderly people with cocci had spent significantly less time in Arizona than controls and were more likely to have congestive heart failure or cancer, to have smoked, or to have taken steroids.	Recent migration to Arizona and underlying medical conditions were associated with increased risk of developing acute cocci among elderly people.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Kolivras et al. 2000. Environmental variability and coccidioidomycosis (valley fever).	Temperature; winds; precipitation; dust; humidity.	Cocci endemic regions	Review	Cocci outbreaks	There is a relationship between temperature, precipitation and cocci outbreaks. Incidence of the disease varies seasonally as well as annually due to changing climatic conditions. Cases of cocci are more likely to disseminate in people under the age of 5 and over the age of 50. Blacks, Asians, Mexicans, Filipinos, and Native Americans are more likely to experience a severe form of valley fever than whites.	Further research is needed on specific conditions that may result in an outbreak of cocci, such as quantitative analysis of cocci incidence and climate data, and developing predictive models. Analysis of cocci incidence in California can be compared to another endemic region to discern different incidence patterns which may provide insights into the distribution of the fungus.
Arsura and Kilgore. 2000. Miliary coccidioidomycosis in the immunocompetent.	N/A	Immunocompetent patients with military cocci; Kern medical center from 1990–97.	Statistical retrospective study	Military cocci (through sputum cultures tissue or body fluid)	Clinical characteristics of military cocci and important aspects of diagnosis and treatment were outlined.	Important diagnostic factors include a history of travel through endemic areas, ethnicity, as well as immunologic status.
Hales et al. 2002. Ciguatera (fish poisoning), El Niño, and Pacific Sea surface temperature	Rainfall Temperature ocean currents	South Pacific Islands	Ecological study	Fish poisoning incidences	Strong positive correlations were found between the annual incidence of fish poisoning and local warming of the sea surface. Ciguatera was found to be the most frequent cause of human illness caused by ingestion of marine toxins.	Marine systems and climate are closely related. Increases in ciguatera may result if the climate continues to warm. Ciguatera may be an indicator of environmental disturbance in tropical marine ecosystems
Puschner et al. 1998. Blue-green algae toxicosis in cattle.	Temperature Wind	Water samples collected from pond where cattle died in Burlington, Colorado	Analytical/ toxicological analysis	Blue-green algal toxins	Blue-green algae toxicosis has been reported following analysis of samples. A strong wind had concentrated algae on one side of the pond to which cattle had access.	Two factors that lead to high concentrations of algae are good growing conditions (warm stagnant water with ample nutrients), and a breeze that blows across the water, allowing the organisms to concentrate near a shore.
Van Dolah, FM. 2000. Marine algal toxins: origins, health effects, and their increased occurrence.	Temperature Wind Precipitation	Marine algal toxins, changes in global distribution, and possible causes of recent increases in occurrence.	Summary	Human intoxication	In addition to foodborne poisonings, toxins from 2 dinoflagellate sources are aerosolized to impact human health through the respiratory route. Over the past 3 decades, the frequency and global distribution of toxic algal incidents appear to have increased and human intoxication from algal sources have occurred.	Marine algal toxins impact human health through seafood consumption and respiratory routes. There is an increase in toxic algal incidents parallels recent evidence of large-scale ecologic disturbances that coincide with trends in global warming. El Niño events have been linked with the occurrence of diseases in marine species.
Joyce, S. 2000. The dead zones: oxygen-starved coastal waters.	Temperature Dissolved O_2 Nutrients (P, N)	A look at dead zones such as the Gulf of Mexico	Review	Hypoxia	During warm months nutrients in excess cause eutrophication which harms aquatic habitats and both marine and human health.	Global decline in water quality is associated with increasing human populations and coastal development.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Harvell et al. 1999. Emerging marine diseases-climate links and anthropogenic factors.	Temperature ENSO events	Analytical	Review	Prevalence of disease of marine taxa.	Climate-mediated physiological stresses may compromise host resistance and increase frequency of opportunistic diseases.	Both climate and human activities may have accelerated global transport of species, bringing together pathogens and previously unexposed host populations.
Ampel and Mosley. 1998. Coccidioidomycocis in Arizona: increase in incidence from 1990– 1995.	Drought Precipitation Temperature	Arizona; 1990–1995/ cases of cocci	Statistical	Cocci incidence	The number of cocci cases increased from 1990 (255 cases) to 1995 (623 cases). Cocci disproportionately affected persons > 65 years and those infected with HIV.	Cocci is a growing health problem in Arizona, and climatic factors may have played an important role in the increase in cocci incidence.
Epstein, P. R. 2001. West Nile virus and the climate.	Temperature Droughts	U.S. Urban dwelling mosquitoes	Analytical review	Cases of West Nile virus	Climatic conditions that amplify diseases that cycle among urban mosquitoes, birds and humans are warm winters and spring droughts.	The extreme weather conditions accompanying long-term climate change may also be contributing to the spread of West Nile virus in the U.S. and Europe.
Hales and de Wet. 2002. Potential effect of population and climate changes on global distribution of dengue fever: an empirical model.	Vapor pressure (measure of humidity)	Modeling of global distribution of dengue fever	Empirical modeling	Cases of dengue fever	About 50%–60% of the projected global population would be at risk for dengue transmission, compared with 35% of the population if climate change did not occur.	Climate change is likely to increase the area of land with a climate suitable for dengue fever transmission putting a large amount of the human population at risk.
Hay et al. 2002. Climate change and the resurgence of malaria in the East African highlands.	Temperature Rainfall Vapor pressure	4 high-altitude sites in East Africa where increases in malaria have been reported in the past 2 decades.	Review	Malaria incidence	Temperature, rainfall, vapor pressure, and the number of months suitable for *P. falciparum* transmission have not changed significantly during the past century or during the period of reported malaria resurgence.	A higher degree of temporal and spatial variation in the climate of East Africa suggests further that claimed associations between local malaria resurgences and regional changes in climate are overly simplistic.
Kistemann et al. 2001. GIS-based analysis of drinking-water supply structures: a module for microbial risk assessment.	Water contaminants	Rhein-Berg district, Germany	GIS study	Incidents and outbreaks of waterborne diseases	GIS application allows a rapid visualization and analysis of drinking water supply, microbial monitoring of raw and drinking water, as well as outbreaks and incidents investigations.	Demand for better health protection and reporting warrants better outbreak management of water-related health impacts of global climate change.
Rodo et al. 2002. ENSO and cholera: a nonstationary link related to climate change?	ENSO SOI (Southern Oscillation index)	Bangladesh at 2 different time periods	Time-series analysis	Cholera prevalence	A relationship was detected between El Niño and cholera prevalence in Bangladesh. Regional changes possibly linked to global warming must be invoked that seem to facilitate ENSO transmission.	There is evidence for an increased role of interannual climate variability on the temporal dynamics of cholera.
Turell et al. 2002. Vector competence of Culex tarsalis from Orange County, California, for West Nile virus.	WNV strain (Crow 397–99)	Females mosquitoes fed on contaminated chicken; Orange County, California	Analytical	WNV transmission	*Cx. tarsalis* mosquitoes were efficient lab vectors of WNV with transmission rates of 81% and 91% for mosquitoes that ingested 10(6.5) and 10(7.3) units of WN/ml of blood, respectively.	*Cx. tarsalis* should be considered a potentially important vector of WNV in the western United States.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Goddard et al. 2002. Vector competence of California mosquitoes for West Nile virus.	WNV strains	10 CA species that are known vectors of arboviruses or major pests.	Analytical	WNV transmission	All 10 species became infected and were able to transmit WNV at some level.	*Culex* species are likely to play the primary role in the enzootic maintenance and transmission of WNV in California.
Hubalek et al. 1999. Surveillance of mosquito-borne viruses in Breclav after the flood of 1997.	Heavy precipitation	July 1997. 11,334 female mosquitoes in 117 pools. South Moravia, the Breclav area in the Czech Republic.	Virological analytical	Virus infection	Data indicate WNV activity in the Breclav area. The WN virus should not be underestimated as a potential agent of local epidemics even in temperate climates.	Environmental factors including human activities which enhance vector population densities (e.g., heavy rains followed by floods, irrigation, higher temperature) can produce an increased incidence of mosquito-borne diseases, including WN fever.
Takeda et al. 2003. Arbovirus surveillance in Rhode Island: assessing potential ecologic and climatic correlates.	Rainfall temperature	1995–2000. Rhode Island. 186,537 mosquitoes were collected from 7 different genera.	Virological analytical	Presence of arboviruses	Total rainfall amounts from May to June were higher than normal in 1996 and 1998. These years showed significantly higher arbovirus activity.	In this study precipitation appeared to be more important than temperature in predicting arbovirus activity.
Weinberg et al. 2003. The U.S. Mexico Border Infectious Disease Surveillance project: Establishing Binational Border Surveillance	Infectious diseases; development of BIDS, a surveillance system for infectious diseases.	In 1997, along the U.S.-Mexico border, an active surveillance system for infectious diseases was implemented.	Analytical	Infectious disease surveillance through serologic testing	BIDS facilitated investigations of dengue fever in Texas-Tamaulipas and measles in California-Baja California. BIDS demonstrates that a binational effort with local, state, and federal participation can create a regional surveillance system that crosses an international border.	Reducing administrative, infrastructure, and political barriers to cross-border public health collaboration will enhance the effectiveness of disease prevention projects such as BIDS.
Doyle et al. 2000. Infectious disease morbidity in the U.S. region bordering Mexico, 1990–1998.	22 nationally notifiable infectious diseases.	U.S.-Mexico border between 1990 and 1998. Disease comparison between border and non-border regions	Analytical	Morbidity due to infectious diseases	Disease rates, reflected as rate ratios, were higher in the border region for botulism, brucellosis, diphtheria, hepatitis A, measles, mumps, rabies, rubella, salmonellosis, and shigellosis than in either of 2 non-border comparison regions.	Results suggest that an inadequate public health infrastructure may contribute to excess morbidity due to infectious diseases in the border region.
Zender et al. 2003. Climate controls on valley fever incidence in Kern County, CA, USA.	Temperature precipitation	Valley fever epidemic; 1991-1995. Kern County, California	Time series	Cocci incidence	Data showed that climate anomalies up to 3 years prior to epidemic affected cocci incidence. A windy month following a wetter than normal season is more likely to result in increased cases. The epidemic was associated with unusually wet periods (9-10 months prior) and with unusually dry, warm, and windy periods (4-6) months prior.	Monthly precipitation, wind speed, and temperature anomalies are the strongest predictive variables explaining up to 20% of incidence anomalies. Wind can act as a dispersal mechanism on soils which have dried for months enhancing cocci incidence.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Alto et al. 2001. Precipitation and temperature effects on populations of *Aedes albopictus* (Diptera: Culicidae): implications for range expansion.	Precipitation Temperature	Caged populations of *Aedes albopictus* (Diptera: Culicidae) maintained at 22°C, 26°C, and 30°C.	Analytical	Population mortality and dynamics	Populations in warmer regions are likely to produce more adults as long as containers do not dry completely. Populations in cooler regions are likely to produce fewer adults with the variability of precipitation contributing less to variation in adult production.	Predicted climate change in North America is likely to extend the northern distribution of *A. albopictus* and to further limit its establishment in arid regions.
Alto et al. 2001. Temperature effects on the dynamics of *Aedes albopictus* (Diptera: Culicidae) populations in the laboratory.	Temperature	Caged populations of *Aedes albopictus* (Skuse) maintained at 22°C, 24°C, and 26°C.	Analytical	Population mortality and dynamics	Results indicated that populations of *Ae. albopictus* occurring in regions with relatively high summer temperatures are likely to have high rates of population growth with populations of adults peaking early in the season. Those with low summer temperatures are likely to have slow, steady production of adults throughout the season with population size peaking later in the season, and may attain higher peak densities of adults.	High temperature conditions, associated with climate change, may increase the rate of spread of *Ae. albopictus* by increasing rates of increase and by enhancing colonization due to rapid population growth.
Lindgren et al. 2001 Tick-borne encephalitis in Sweden and climate change.	Temperature	Sweden, 1960–1998. Since the late 1950s, all cases of encephalitis admitted in Stockholm County have been serologically tested for TBE.	Statistical, multiple regression	Increase in tick-borne encephalitis (TBE) incidence	The incidence of TBE in Sweden has substantially increased since the mid-1980s. The climate has become milder and ticks have become more abundant. Increases in disease incidence was significantly related (R(2)=0.58) to a combination of two consecutive mild winters, temperatures favoring spring development (8°C–10°C) and extended autumn activity (5°C–8°C) in the year prior to the incidence year, and temperatures allowing tick activity (5°C–8°C) early in the incidence year.	The data indicate that the increase in TBE incidence since the mid-1980s is related to the period's change towards milder winters and early arrival of spring. Other factors such as more people in endemic areas, and increases in host animal populations, may have added to the cases. Access to vaccines since 1986 and increased awareness of ticks might have led to underestimate the disease link. Other tick-borne diseases might have been affected by the milder climate.
Zeitz et al. 1995. A case-control study of hantavirus pulmonary syndrome during an outbreak in the southwestern United States.	HPS	May 1993, HPS outbreak in southwestern U.S. 17 case-patients were compared with 3 groups of controls	Statistical analysis, case-control study	Hantavirus cases	More small rodents were found at case households than at near or far control households. Case-patients were more likely than household controls to hand plow (OR=12.3) or to clean feed storage areas (OR=33.4). Case-patients were more likely than near controls to plant (OR= 6.2) and more likely than far controls to clean animal sheds (OR=11.9).	Peridomestic cleaning, agricultural activities, and an increased number of small rodents at the household were associated with HPS.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Infectious Diseases (cont.)						
Glass et al. 2000. Using remotely sensed data to identify areas at risk for hantavirus pulmonary syndrome	Precipitation Elevation data	1993 HPS outbreak. Precipitation and elevation data during the 6 previous years.	Logistic regression statistical analysis, case-control study.	HPS cases	Rainfall at case sites was not higher during 1992–1993 than in previous years. However, elevation, as well as satellite data, showed an association between environmental conditions and HPS risk the following year.	The 1993 HPS outbreak was attributed to environmental conditions and increased rodent populations caused by unusual weather in 1991–1992. Repeated analysis using satellite imagery from 1995 showed substantial decrease in medium- to high-risk areas. Only one case of HPS was identified in 1996.
Reisen et al. 1993. Effect of temperature on the transmission of western equine encephalomyelitis and St. Louis encephalitis viruses by *Culex tarsalis* (Diptera: Culicidae).	Temperature	*Cx. tarsalis* females; San Joaquin valley and Coachella valley	Analytical	Transmission rates	Temperatures in the San Joaquin Valley averaged 5°C cooler than the Coachella valley , thereby shortening the duration of potential transmission season for WEE virus form 10 to 8 months and for SLE virus from 8 to 5 months.	Incubation rate of WEE and SLE viruses increased as incubation temperatures increased from 10 to 30 degrees C.
Reisen, W. K. 1995. Effect of temperature on *Culex Tarsalis* (Diptera: Culicidae) from the Coachella and San Joaquin Valleys of California.	Temperature	*Cx. tarsalis* females were collected in 1991 and 1993, reared and maintained at 5 different temps.	Analytical	Survivorship and developmental rates of mosquitoes	Mosquitoes exhibited mid-summer changes in immature development rates and survivorship, adult wing length, life expectancy at emergence, and generation time.	Temperature may be a factor in both spatial and temporal changes in mosquito biology.
Wegbreit et al. 2000. Relationships among weather, mosquito abundance, and encephalitis virus activity in California: Kern County 1990–1998.	Rainfall; snow depth; water content and runoff of the Kern River.	*Cx. tarsalis* in Kern County, summertime, 1990–1998	Statistical regression analysis	Mosquito abundance and WEE cases	Total monthly rain that fell during winter explained only 13% of the variability in mosquito abundance, where river runoff 1 month earlier explained 67%, and water content of snowpack during winter explained 70% of the abundance during the following summer. After being absent from Kern County since 1983, WEE returned during the wet years of 1996–1998.	Water content of snow in the Sierra Nevada during winter provided an excellent early warning of river runoff, mosquito abundance and WEE activity levels on the floor of the San Joaquin Valley. In CA, the mosquito summer abundance was linked to rainfall, snow depth, water content, and river runoff.
Other Health-Related Sectors						
Beuhler, M. 2003. Potential impacts of global warming on water resources in southern California.	Temperature Precipitation	Southern California, water resources	Review	Warming; floods; sea-level rise; droughts; shift from snowfall to rain.	Rising sea levels will exacerbate salt-water intrusion into freshwater and impact the quality of surface water supplies. Integrated water resources is an appropriate strategy least vulnerable to the impacts of climate change.	Arid and semi-arid regions like Southern CA are most vulnerable to anticipated negative impacts of global warming on water resources. Planning for future water needs should include potential considerations of a climate change.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Other Health-Related Sectors (cont.)						
Steding et al. 2000. New isotopic evidence for chronic lead contamination in the SF Bay estuary system: implications for the persistence of past industrial lead emissions in the biosphere.	Precipitation	San Francisco Bay waters and their major fluvial inputs	Mathematical	Lead isotope compositions	Isotopic compositions of bay waters showed spatial variation from southern to northern reach. Historic gasoline deposits may remain in the combined riparian/estuarine system for decades.	The link between climate and contaminant transport suggests local or global climate change will affect the distribution and fate of contaminants.
Stott et al. 2000. Increased dissolved oxygen in Pacific intermediate waters due to lower rates of carbon oxidation in sediments.	Temperature Dissolved oxygen	Sediments in the Northeastern Pacific Ocean (Santa Barbara, Santa Monica, and Alfonso Basin)	Mathematical	Carbon isotope composition of benthic foraminifers. Carbon oxidation rate	Twofold decrease in the carbon oxidation rate (equivalent in an increase in dissolved oxygen concentrations of 15–20 micromoles per liter)	Climate effects on surface productivity, reducing the supply organic matter to sediments, may have had a greater effect on benthic oxygen levels than changes in ocean circulation patterns.
Bradman and Harnly. 1997. Pesticide exposures to children from CA's Central Valley: results of a pilot study.	Dust	House dust samples from rural children's homes. California Central Valley	Pilot study. (pesticide analysis)	Children's pesticides exposures	10 of 33 pesticides tested in house dust were detected. There was a difference in exposure between farmers and non-farmers homes. The sources of the compounds could not be determined.	Pesticide residues are present in the home environment of some CA children and are less likely to contribute to exposures. Additional research is needed to assess the associated risks.
Stephens, T. 2002. New climate study shows California's vulnerability to global warming.	Temperature Precipitation Changing [CO_2]	California; modeling-regional and global	Statistical	Effects of doubling [CO_2] in the atmosphere vs. preindustrial levels	Greatest temperature increases occurred at high elevations in the Sierra Nevada and the Cascade range. Rainfall increased in Northern California, but remained about the same in the South.	Global warming will mean warmer temperatures and smaller snowpacks in CA with serious adverse effects on the state's water supply. Regional variations apply.
Krotz, D. 2002. New study projects climate change's impact on California's watersheds.	Temperature precipitation	California; modeling	Statistical	Climate change impacts on water resources (soil moisture, snowpack, snowmelt)	By 2100, the April 1measurement of the amount of water stored in the snowpack decreased by about 50% for all watersheds except the very high elevation Kings River.	The possibility of significant changes to water resources may prompt state officials to rethink farming and suburban development patterns, as well as reservoir operating rules.
Snyder et al. 2002. Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulnerable region.	Atmospheric CO_2	California- regional climate model: 280 and 560 ppm CO_2	Sensitivity study	Climate responses (precipitation, temperature, snow)	Relative to the 280 ppm results, 560 ppm results show temperature increasing everywhere in the region annually (up to 3.8°C), and in every month, with the greatest monthly surface warming at high elevations. Snow accumulation decreased everywhere, and precipitation increased in northern regions by up to 23%, on a mean annual basis.	Global modeling studies of future climate change predict large scale climatic responses to increased atmospheric carbon dioxide (CO_2).

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Disaster Planning						
Shoaf et al. 2000. Survey research in disaster public health.	Disasters	Data collected from phone interviews following California earthquakes	Analytical	Disaster preparedness level	In the Northridge earthquake, those over age 60 were 3 times more likely to be hospitalized or die as a result of injuries than were those aged 20–59.	It is possible to track the changes in preparedness levels across time, as well as compare injury rates or other impacts across time, place, and disaster type. Risk factors can also be identified for health outcomes.
Abbott. 2000. Disaster public health considerations.	Floods; earthquakes; man-made disasters.	California	Descriptive / review	General public health effects. Public and environmental health control measures.	Health problems occur at varying times during a disaster, but those with sufficient warnings result in fewer injuries and deaths. Disasters disrupt the infrastructure, seriously impacting transportation, sanitation, housing, communications, electricity, and more.	Medical and health response functions were identified that must be planned for and carried out following disasters.
Pope, T. 1994. Natural Disasters: How to Resume Operations and Prioritize your Infrastructure.	Natural disasters: hurricanes, floods, earthquakes…	Managed care organization , U.S.	Review discussion	Delivery of health care. Maintaining integrity of the organization	Disaster planning includes establishing recovery teams (e.g., means to reach people should phone lines be severed); backing information systems; developing back-up and alternative systems for water, power, and sanitation.	Well-planned disaster contingency plans enable rapid full recovery. The essential parts of the planning include the headquarters, the computer system, utilities, and communication.
Pope, T. 1994. Patient Care During Natural Disasters.	Natural disasters: hurricanes, floods, earthquakes…	HMOs in the U.S.	Review discussion	Patient care delivery	The ability to reroute services to alternative care centers is crucial in disaster management. ERs should focus on disaster relief. Extra care calls should be anticipated as well as a different mix of patients.	Contingency plans, flexibility, and system-wide shifting of services are crucial for disaster management.
Pesik and Keim. 2002. Logistical considerations for emergency response resources.	Natural disaster	General	Review Discussion	Needed resources within a disaster	Resource management is a crucial component of disaster preparedness and response. These are: understanding the public health consequences of disasters and the associated morbidity and mortality patterns, completion of a vulnerability assessment, identifying sources of outside aid and coordination among multiple agencies.	Immediate needs fall within the medical sector. Disaster planning and resource management should consider both short-term and long-term needs and consequences of a disaster.
Vulnerable populations						
Bunyavanich et al. 2003. The impact of climate change on child health.	Temperature Precipitation Air pollution UV radiation	Children	Review	Climate impact on child health	Environmental and ecological changes triggered by climate change can lead to respiratory diseases (asthma), sunburn, heat stroke, melanoma, drowning, and immunosuppression, as well as diseases such as gastrointestinal and psychosocial; it can also increase rates of malnutrition, allergies and exposure to toxins, vectorborne (malaria, dengue, encephalitis, Lyme), and emerging infectious diseases.	Proactive and preventive physician action, research focused on the differential effects of climate change on subpopulations including children, and policy advocacy on the individual and federal levels could contain climate change and inform appropriate prevention and response.

Author and Title	Exposure/ Climate Variables	Study Population and Location	Study Type	Health Outcomes	Results	Comments and Recommendations
Vulnerable populations (cont.)						
Garza, D. 2001. Alaska Natives assessing the health of their environment.	Contaminants Climate change	Alaska, Native populations	Review	Decline in general health	Contaminants are showing up in the animals, fish and waters that Natives use. Alaska natives no longer believe that wild resources are the best and many are turning to alternative foods.	Changes in Alaska's ecosystems caused by pollution, contaminants and global climate change are adversely impacting rural residents and natives who rely on natural resources for food, culture, and community identity.